EXPERIMENTAL INVESTIGATION OF FATIGUE STRENGTH OF LIGHTWEIGHT CONCRETE IN SEA WATER

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ABSTRACT

Fatigue is an important design consideration in many structures. Lightweight concrete is a promising material in the construction industry particularly in the offshore structures and structures subjected to dynamic loading.

This report presents the results of an extensive experimental investigation to study the flexural fatigue strength, endurance limit, and static flexural strength of lightweight concrete in sea water. The concrete beams were made at the University of New Brunswick, Canada. A total of six mixes, FW_1 to FW_6 were investigated in this study. A total of 120 beams, 20 beams in each group 76 X 102 X 406 mm (3 X 4 X 16) inches, were tested for flexural fatigue with load applied at one third points and at a frequency of loading of 20 cycles per second (HZ). The beams which survived two million cycles of non reversed fatigue loading were tested in static flexure to determine their residual strength (modulus of rupture).

The static flexural strength (modulus of rupture) varied from 7.59 MPa (1100 Psi) to 8.79 MPa (1275 Psi). The fatigue strength varied from 5.10 MPa (740 Psi) to 5.58 MPa (810 Psi). The endurance limit (the ratio of fatigue strength to modulus of rupture) varied from 0.59 to 0.72. There was an increase in residual static flexural strength for the groups FW_3, FW_5 and FW_6. A comparison of the flexural fatigue strengths of lightweight concretes of equal mix proportions and equal compressive strengths, had shown that the specimens tested in the sea water had slightly higher fatigue strength and higher modulus of rupture. However the endurance limit, the ratio of flexural fatigue strength to modulus of rupture was nearly the same to both the concretes.

INTRODUCTION

Lightweight concrete with a low unit weight (1970-1995 kg/m^3) and high compressive strength up to 50 MPa (7250 Psi) is an important building material in the modern construction. Structural lightweight concrete is a more versatile material with many advantages over the normal weight concrete, reducing self weight of the building members and lowering foundation construction costs in high rise buildings. Lower erection and transportation costs are also achieved with lightweight concrete. In general lightweight concrete is more resistant to fire, and provides better heat and sound insulation.

STATEMENT OF THE PROBLEM

A perusal of literature has shown that there has not been any investigation about the flexural fatigue strength of lightweight concrete in sea water. Because there is a high potential for using lightweight high strength concrete in offshore structures and other structures that could be partly or fully immersed in water. There is a need to know about the behavior of this material when subjected to fatigue loading when immersed in water. This study was mainly aimed at studying the flexural fatigue strength, endurance limit, and the static flexural strength of this material in sea water.

OBJECTIVE OF INVESTIGATION

The primary objective of this investigation was to determine the behavior and endurance limit of lightweight concrete when subjected to non reversed fatigue loading in sea water, and to compare these results with the results already obtained by the testing the same six concretes for fatigue flexural strength in air.

SIGNIFICANCE OF THE INVESTIGATION

Until a short time ago, the main use of the structural lightweight concrete was for short span slabs, framing between steel beams, with specified strengths. With the development of modern construction, the use of high strength lightweight concrete is tremendously increasing in marine (offshore) structures because of its greatly reduced submerged weight. In particular, it can be adopted in seismic environment because of the significant reduction in dead weight.

In many of the applications mentioned earlier, particularly in structures subjected to dynamic loading (off shore structures), the flexural fatigue strength and the endurance limit are the important design parameters, because these structures are to be designed mainly on the basis of fatigue cycles. Therefore this investigation is specifically aimed to determine the flexural fatigue strength of high strength light weight concrete.

MATERIALS

The fine aggregate used was natural sand obtained from the Blagdon pit. The coarse aggregate was a lightweight expanded shale from Minto, N.B. and was supplied by Modern Enterprises of Salisbury, N.B. The aggregate was produced using a rotary kiln. Results of tests carried out on the aggregate are given in the table I & II in the Appendix..

CEMENT

Type 10 cement satisfying Canad standards was used, supplied by Canada cement Lafarge Ltd. The chemical analysis of the cement, produced at their Brookfield, Nova Scotia plant is included in the Appendix in table III.

AIR ENTRAINING AGENT

The air entraining agent was Daravair, a neutralized vinsol resin with 20% total solids supplied by W.R. Grace.

HIGH RANGE WATER REDUCING AGENT (HRWR)

The WRDA 19 used was a naphthalene based superplasticizer, manufactured by W.R. Grace.

SEA WATER PREPARATION

The substitute ocean water was prepared according to the ASTM standard specifications, (ASTM D 1141 - 86).

Two stock solutions were prepared separately (stock solution 1 and stock solution 2). Stock solution 1 was prepared by dissolving the required amounts of $MgCl_2.6H_2O$, $CaCl_2$ and $SrCl_2.6H_2O$ in distilled water and diluting it to a total volume of 800 ml. Stock solution 2 was prepared by dissolving the required amounts of KCl, $NaHCo_3$, KBr, H_3Bo_3 and NaF in distilled water diluting it to a total volume of 1500 ml.

To prepare 70 liters of sea water 1700 gms of NaCl and 300 gms of Na_2So_4 was dissolved in distilled water and slowly with vigorous stirring 700 ml of stock solution 1 and 1400 ml of stock solution 2 were added and the whole contents were diluted to a total volume of 70 liters. The Ph was adjusted to 8.2 with 0.1N NaoH solution. The amounts of chemicals used are given in the Appendix in table VIII.

Test Specimens

Three different mixtures were used with three different cement contents (415, 465 and 515 kg/m^3); these mixtures were designated as mixtures 1, 2 and 3 respectively. Two batches were made for each mixture and these batches were named as mixes FW_1, FW_2, FW_3, FW_4, FW_5 and FW_6. Twenty beams

were made from each batch for flexural fatigue and modulus of rupture testing.

The specimens were made at the university of New Brunswick, Canada and sent to rapid city after they were initially cured. The specimens were received in well insulated and sealed wooden boxes in Rapid City. They were fully moist and approximately 10 % relative humidity was maintained during their transit. The boxes were opened and the specimens were immediately immersed in water, the water was constantly maintained at a temperature 22 ± 1°C (72 ± 1°F). They were cured in water until the time of testing. The specimens were always kept in wet condition and were never allowed to dry at any time till the testing was completed.

Testing of the plastic concrete

Prior to casting, the fresh concrete was tested for air content and unit weight. The temperature of the concrete was measured using a steel jacketed thermometer. The properties of the plastic concrete are given in table IV in the Appendix.

TESTING OF HARDENED CONCRETE

The mass density at 1 day of the 150 x 300 mm (6 X 12 inches) cylinders and the 76 x 102 x 406 mm (3 X 4 X 16 inches) Prisms were measured and are given in the Appendix

in table V. Using the unit weight of the concrete and the batch proportions, the mix proportions per cubic meter was calculated and are given in Appendix in table V. The weights of the fine aggregates are given in a saturated surface-dry moisture condition and the coarse aggregate in surface dry condition after 24 hours of soaking in water. The compressive strengths at 7 and 28 days are given in the Appendix in table VI.

Static Flexure Test

Shortly before fatigue testing, Static flexure tests were conducted using third point loading with a span of 304 mm (12 inches) on four randomly chosen specimen from each batch to estimate the average modulus of rupture of the concrete. The load levels used in fatigue testing were determined from these results. The test specimens were totally immersed in sea water during the entire testing operation.

Flexural Fatigue Test

The same testing arrangement (304 mm span and third point loading) was used for the flexural fatigue testing. The beams were subjected to a non reversed fluctuating load. All the beams were totally immersed in a steel tank containing the sea water as shown in the photographs 1 & 2.

The procedure used for the test was as follows. The lower load limit was set at 10 % of the average maximum load obtained from the static flexure test. For the first beam in each mix the upper load limit was set at 90 % of the average maximum flexural load and the fatigue test was conducted between these two limits. If the beam failed before completing two million cycles, the upper limit was reduced for the next specimen. If the beam did not fail, another beam was tested at the same upper load as a replicate. Three specimens were tested at each maximum load level.

The frequency of loading used was 20 cycles per second. The MTS machine was used for all the tests. The control and the monitor system consists of a MTS 436 control unit, a Hewlett Packard Oscilloscope and a digital multimeter working with a MTS load cell. There was also a counter provided to keep track of the number of cycles to the nearest 100. When the beam failed the counter reading was recorded and multiplied by 100 to give the number of cycles to which the beam has been subjected. A mechanical cutoff switch was provided which could turn off the machine when the beam broke.

TEST RESULTS AND DISCUSSIONS

Three different cement contents were used namely 415, 465, and 515 kg/m^3 ; these mixtures were designated as Mix 1, Mix2, and Mix3 respectively. Two batches were made for

each mixture and these batches were named as FW_1, FW_2, FW_3, FW_4, FW_5, and FW_6. The fatigue test results are given in tables 1 - 6 and 1A - 2A for groups FW_1-FW_6 respectively. The modulus of rupture test results before fatigue, and after fatigue are given in tables 7 - 12 for the groups FW_1-FW_6 respectively. All these tests were also performed under sea water in exactly the same conditions as the fatigue tests.

Flexural Strength (Modulus of rupture)

The test results for modulus of rupture for specimens made from all the concretes are presented in tables 7 - 12. The average values of modulus of rupture before fatigue were 7.83 MPa (1135 Psi), 8.31 MPa (1205 Psi), 8.14 MPa (1181 Psi), 8.07 MPa (1171 Psi), 8.17 MPa (1185 Psi), and 7.89 MPa (1145 Psi) respectively for the groups FW_1 - FW_6. The modulus of rupture for group 2 (mix 1) is 6% more than the that of group 1 (mix 1), and all the other groups had almost the same modulus of rupture. In tables 14 & 14A, the modulus of rupture values for the six groups are combined. The average modulus of rupture before fatigue for all the six groups combined together was found to be 8.10 MPa (1175 Psi).

Flexural Fatigue Strength

The fatigue test results are given in tables 1 - 6 and 1A - 6A. Graphs were drawn to show various relationships between the number of cycles, the logarithm of the number of cycles, fatigue strength and endurance limits. Based on these results and figures, the following aspects are discussed.

Fatigue Strength

Fatigue strength is defined as the maximum fatigue flexural stress at which the beam can withstand two million cycles of non reversed fatigue loading. Though the modulus of rupture for group FW_1 was slightly less than that of group FW_2, the flexural fatigue strength was observed to be the same for the groups FW_1 and FW_2. The compressive strengths were almost the same for all the groups. Graphs were drawn showing the relationship between the ratio of flexural fatigue stress to modulus of rupture (fmax/fr) and the number of cycles N, (fmax/fr) Vs Log N, fmax Vs N, fmax Vs Log N, for all the groups FW_1 - FW_6. The shape of the curves and the pattern of the relationships are the same for all the concretes. The flexural fatigue strengths and the endurance limits are obtained from these figures. Graphs of fatigue flexural stress versus the number of cycles are shown for groups FW_1 - FW_6, the relationship is non linear till the fatigue strength of that particular concrete is reached and then the line becomes parallel to the X-axis. The same behavior was observed for all the groups. Graphs

were also plotted for the flexural fatigue strength versus Log of number of cycles; these figures show a linear relationship between fatigue stress and Log of number of cycles up to the fatigue stress of that particular concrete and then the line becomes parallel to the X-axis.

Endurance Limit Expressed As A Percentage of It's modulus of rupture

Endurance limit of concrete can be defined as the fatigue flexural stress at which the beam could withstand two million cycles of non reversed fatigue loading, expressed as the percentage of it's modulus of rupture. The endurance limit of the mixes varied between 0.59 - 0.72. Graphs of ratio of maximum flexural fatigue stress to average static flexural stress versus number of cycles were drawn for the six different groups FW_1 - FW_6. It is observed that the relation is non linear up to the fatigue strength of that particular group, then the line becomes parallel to X - axis. Graphs were also drawn for endurance limit versus logarithm of number of cycles for batches FW_1 - FW_6.

The average endurance limit for the groups FW_1 - FW_6 are 0.66, 0.62, 0.63, 0.59, 0.68 and 0.72 respectively. It is known that endurance limit for normal weight concrete varies from 0.55 - 0.65; a slightly higher value was obtained for the lightweight concrete in this investigation.

Mode of Failure

Visual examination showed that there was no difference in the failure surfaces of the specimens tested in modulus of rupture and the specimens tested in fatigue for all the concretes. It was also observed that the lightweight aggregate fractured in all cases indicating that there was no interfacial bond failure in all the specimens. The final failure (fracture) occurred in the constant moment zone within the middle third of the beam indicating that all failures are flexure failures, and they are not influenced by shear.

Static Flexure Test After Fatigue

The static flexure test was also performed on those beams which were subjected to 2 million cycles of non reversed fatigue loading and did not fail. Tables 7 - 12 give the corresponding static flexural test results before and after fatigue. The modulus of rupture values were observed to be 7.59 MPa (1100 Psi), 7.93 MPa (1150 Psi), 8.50 MPa (1233 Psi), 7.97 MPa (1155 Psi), 8.79 MPa (1275 Psi), and 8.79 MPa (1275 Psi) for the six different groups FW_1-FW_6 respectively. The static flexural strengths after fatigue slightly decreased for group FW_1, FW_2, and FW_4, the reductions were 3%, 5% and 2%, and increased for the groups FW_3, FW_5, and FW_6. The percentage increase was 4.5%, 8%, and 11% respectively.

CONCLUSIONS

Based on the results of the experimental investigation, and analysis of results, the following conclusions could be drawn.

1. The endurance limit, the ratio of maximum fatigue flexural stress for which the beam can withstand two million cycles of fatigue loading, to its modulus of rupture is 0.65 for the lightweight concrete under sea water.

2. The flexural fatigue strength of lightweight concrete, the maximum flexural fatigue stress to which the beam can be subjected to two million cycles of fatigue loading without failure was about 5.2 MPa (750 Psi), the compressive strength being about 48.30 MPa (7000 Psi).

3. The variation of cement content from 415 to 515 kg/m^3 (699 to 867.9 lb/yd^3) had produced only a slight increase in compressive strength about 2.07 MPa (300 Psi).

4. An inspection of the fractured surfaces had shown that there was no interfacial bond failure and all the lightweight aggregates in the failed cross sections had fractured in all specimens weather they failed in flexure or in fatigue.

5. A comparison of the flexural fatigue strengths of lightweight concretes of equal mix proportions and equal compressive strengths, had shown that the specimens tested in sea water had slightly higher fatigue strength and higher modulus of rupture. However the endurance limit, the ratio of flexural fatigue strength to modulus of rupture, was nearly the same for both the concretes.

CANMET CONTRACT

Mix	Cement (Kg/m^3)	Air	CANMET Notation	Casting date
FW 1	415	5.0	MIX 1	01-04-90
2	415	5.0		"
FW 3	465	5.0	MIX2	01-05-90
4	465	5.0		"
FW 5	405	5.0	MIX3	01-06-90
6	405	5.0		"

Concrete Mix description

Mix	Cement Content (Kg/m^3)
FW 1	415
2	415
FW 3	465
4	465
FW 5	515
6	515

TABLE I

Sieve Analysis of Fine Aggregate

Sieve Size	Passing	CSA % Passing
5 mm	98	95-100
2.5 mm	93	80-100
1.25 mm	74	50-90
630 mm	42	25-65
315 mm	18	10-35
160 mm	5	2-10
PAN	0	0

TABLE II

Sieve Analysis of Coarse Aggregate-Melite

Sieve Size	% Passing
20 mm	100
14 mm	82
10 mm	45
5 mm	8
PAN	0

Adsorption at 24 hours: specific gravity = 1.78

moisture content = 6.49%

TABLE III

Test results on materials used

Physical properties and chemical analysis of cement	
Description of tests	Portland Cement CSA Type 10
Physical tests - fineness	
Fineness - Passing 75 mm, %	--
Passing 45 mm, %	86.8
blaine, m^2/kg	385
Normal consistency, %	--
Setting time, min	124
Autoclave expansion, %	0.05
Physical tests - Mortar strength	
Water content, %	--
Flow %	--
Compressive strength, MPa	
3-day	29.9
7-day	34.6
28-day	40.2
Pozzolanic activity with portland cement, %	--
Water requirement % of control	--
Pozzolanic activity with lime, MPa	--
Chemical analysis	
SiO_2, %	19.75
CaO, %	63.05
CaO (free) %	0.66
Insoluble %	--
LOI, %	2.65
Al_2O_3, %	5.39
Fe_2O_3, %	2.02
SO_3, %	4.13
MgO, %	1.35
Na_2O, %	--
K2O, %	--
Alkalies (as Na_2O), %	0.86
$CaSO_4$, %	--
C_3A, %	--

TABLE 1V

Properties of Plastic Concrete

Mix	Cast Date	Air (%) content	Unit Wt (Kg/m^3)	Slump A	Slump B	Concrete temp
FW 1	01-01-90	5.0	1972	32	70	22
2		4.0	1985	22	80	22
FW 3	01-05-90	5.5	1964	27	72	22
4		4.5	1936	37	72	22
FW 5	01-06-90	4.2	1992	27	68	24
6		4.3	1991	33	77	23

(A) Before HRWR addition

(B) After HRWR addition

TABLE V

Mix Proportions in Kg/m^3 (unless otherwise noted)

Mix	Cement	Water	F.A.	C.A.	AREA ml/m^3	HRWR ml/m^3
FW 1	421	168	734	645	195	2651
FW 2	420	183	733	647	215	3476
FW 3	464	170	705	625	257	1682
FW 4	455	173	692	614	257	1392
FW 5	518	183	684	606	285	2591
FW 6	518	189	684	606	285	2420

TABLE VI

Compressive Strength in (MPa)

Cylinder No.		28 days	Cylinder No		28 days
FW_1-	1		FW_2-	1	
	2	45.5		2	51.5
	3			3	
	4	46.2		4	47.4
	5			5	
	6	48.3		6	49.3
Averages		46.7			49.4
FW_3-	1		FW_4-	1	
	2	47.5		2	47.9
	3			3	
	4	51.3		4	49.6
	5			5	
	6	48.6		6	48.5
Averages		49.2			48.7
FW_5-	1		FW_6-	1	
	2	48.9		2	51.9
	3			3	
	4	48.9		4	50.6
	5			5	
	6	51.1		6	50.8
Averages		49.6			51.1

TABLE VII

Mass Density at 1 day (Kg/m^3)

Mix No	FW_1	FW_2	FW_3	FW_4	FW_5	FW_6
Prisms						
1	2001	2013	2004	1979	2011	2013
2	2005	2016	2005	1981	2010	1999
3	2011	2019	2015	1977	2020	2013
4	2011	2024	2012	1986	2016	2024
5	2010	2023	2008	1985	2012	2023
6	2011	2024	2014	1988	2016	2025
7	2014	2016	2013	1997	2013	2021
8	2017	2022	2013	1990	2016	2022
9	2008	2027	2012	1990	2020	2019
10	2007	2018	2016	1990	2022	2023
11	2013	2019	2015	1987	2020	2019
12	2025	2016	2014	1984	1983	2023
13	2018	2026	2022	1983	2022	2024
14	2020	2020	2018	1978	2022	2027
15	2016	2029	2020	1978	2026	2027
16	2021	2028	2024	1995	2020	2025
17	2020	2017	2020	1984	2016	2028
18	2012	2024	2027	1989	2014	2029
19	2023	2025	2029	1993	2015	2024
20	2021	2024	2030	1990	2018	2029
21	2017	2025	2032	1988		
22	2021			2007		
23	2018					
Averages	2015	2022	2017	1987	2016	2022
Cylinders						
1	2015	2024	2015	1991	2006	2014
2	2006	2024	2007	1992	2018	2019
3	2013	2025	2003	1998	2005	2014
4	2018	2028	2024	2002	2015	2025
5	2021	2032	2021	1993	2015	2035
6	2017	2025	2038	1996	2029	2034
Averages	2015	2026	2018	1995	2015	2025

TABLE VIII

To prepare 70 liters of substitute sea water

the quantities of chemicals required are

Stock Solution No 1	Quantity (gms)
$MgCl_2.6H_2O$	388.9
$CaCl_2$	40.5
$SrCl_2.6H_2O$	1.48
Stock Solution No 2	
KCl	104.2
$NaHCO_3$	30.15
KBr	15
H_3BO_3	4.05
NaF	0.45
NaCl	1717.38
Na_2SO_4	286.58
(Few drops of 0.1N NaOH Solution)	

TABLE 1. FATIGUE TEST RESULTS
FOR MIX FW_1

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		DYNAMIC LOAD	
			WIDTH	DEPTH	MAX. LBS.	MIN. LBS.
FW_1-3	4-11-90		3.103	4.003	3164	748
FW_1-1	4-10-90		3.119	4.025	2992	690
FW_1-8	4-06-90		3.106	3.998	2991	690
FW_1-12	4-08-90		3.065	4.020	3164	748
FW_1-18	4-07-90		3.043	4.001	2991	690
FW_1-16	4-09-90		3.056	4.013	3164	748
FW_1-13	4-12-90		3.046	3.998	2992	690
FW_1-2	4-07-90		3.045	4.010	3682	920
FW_1-4	4-09-90		3.046	4.005	3164	748
FW_1-6	4-06-90		3.033	4.018	3337	805
FW_1-7	4-07-90		3.020	4.021	3682	920
FW_1-9	4-10-90		3.086	3.976	2992	690
FW_1-11	4-05-90		3.074	4.017	3682	920
FW_1-14	4-05-90		3.045	4.050	3337	805
FW_1-17	4-05-90		2.971	4.025	3337	805

TABLE 1A. FATIGUE TEST RESULTS

FOR MIX -- FW_1

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_1-7	907	226	681	0.80	3300
FW_1-2	902	224	678	0.79	4700
FW_1-11	893	222	671	0.79	12100
FW_1-17	835	201	634	0.74	1046500
FW_1-6	820	201	619	0.72	4500
FW_1-14	810	201	609	0.71	6400
FW_1-4	779	185	594	0.69	62300
FW_1-16	775	182	593	0.68	2000100 +
FW_1-12	766	180	586	0.67	2000100 +
FW_1-3	765	180	585	0.67	2000100 +
FW_1-9	736	170	566	0.65	30500
FW_1-13	743	172	571	0.65	2000100 +
FW_1-18	738	169	569	0.65	2000100 +
FW_1-8	724	167	557	0.64	2000100 +
FW_1-1	711	164	547	0.63	2000100 +

Average fexural strength fr = 1135 psi (from table no 1.)

+ Beams crossed 2 million cycles

TABLE 2. FATIGUE TEST RESULTS FOR MIX FW_2

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		DYNAMIC LOAD	
			WIDTH	DEPTH	MAX. LBS.	MIN. LBS.
FW_2-5	4-15-90		2.983	4.012	3020	678
FW_2-6	4-17-90		2.973	4.025	3020	678
FW_2-12	4-13-90		3.003	4.027	3204	740
FW_2-16	4-14-90		3.067	4.000	2835	617
FW_2-18	4-16-90		3.023	4.013	3020	678
FW_2-1	4-17-90		3.055	4.030	3020	678
FW_2- 2	4-13-90		3.033	3.990	3574	863
FW_2-4	4-13-90		3.086	4.023	3204	740
FW_2-8	4-13-90		3.073	3.985	3574	863
FW_2-10	4-13-90		3.073	4.011	3944	986
FW_2-11	4-13-90		3.048	4.000	3944	986
FW_2-14	4-13-90		3.006	4.012	3944	986
FW_2-15	4-13-90		3.031	4.016	3574	863
FW_2-17	4-18-90		3.052	4.013	3389	802
FW_2-19	4-14-90		3.055	4.013	3389	802
FW_2-20	4-13-90		2.986	4.005	3204	740

TABLE 2A. FATIGUE TEST RESULTS

FOR MIX -- FW_2

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_2-11	973	242	731	0.81	5
FW_2-14	973	242	731	0.81	6400
FW_2-10	960	240	720	0.79	2
FW_2-2	910	188	722	0.75	12300
FW_2-8	879	212	667	0.73	900
FW_2-15	877	212	665	0.73	52300
FW_2-17	827	196	631	0.68	14900
FW_2-19	827	196	631	0.68	43400
FW_2-20	803	188	615	0.66	9100
FW_2-12	789	182	607	0.65	2000100 +
FW_2-4	770	177	593	0.64	79400
FW_2-5	755	169	586	0.63	2000100 +
FW_2-6	752	171	581	0.62	2000100 +
FW_2-18	744	167	577	0.62	2000100 +
FW_2-1	730	164	566	0.60	77200
FW2-16	693	151	542	0.57	2000100 +

Average fexural strength fr = 1205 psi (from table no 2.)

+ Beams crossed 2 million cycles

TABLE 3. FATIGUE TEST RESULTS
FOR MIX FW_3

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		DYNAMIC LOAD	
			WIDTH	DEPTH	MAX. LBS.	MIN. LBS.
FW_3-1	4-20-90		3.057	4.000	3164	487
FW_3-2	4-18-90		3.050	4.007	3408	487
FW_3-3	4-18-90		3.028	4.003	4381	487
FW_3-4	4-18-90		3.090	4.001	4381	487
FW_3-6	4-22-90		3.047	4.013	3408	487
FW_3-7	4-22-90		3.037	4.015	3408	487
FW_3-8	4-20-90		3.001	4.020	3164	487
FW_3-9	4-18-90		3.101	4.010	4381	487
FW_3-10	4-20-90		3.095	4.003	2921	487
FW_3-11	4-18-90		3.090	4.030	2921	487
FW_3-12	4-22-90		3.070	4.025	3894	487
FW_3-13	4-19-90		3.062	3.973	3164	487
FW_3-16	4-18-90		3.062	4.013	3894	487
FW_3-17	4-18-90		3.053	4.000	3894	487
FW_3-18	4-22-90		3.060	4.020	3164	487
FW3-19	4-21-90		3.035	4.000	2921	487

TABLE 3A. FATIGUE TEST RESULTS

FOR MIX -- FW_3

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_3-3	1083	120	963	0.92	1100
FW_3-9	1054	117	937	0.89	5
FW_3-17	957	120	837	0.81	1046500
FW_3-16	948	119	829	0.80	6900
FW3-12	939	118	821	0.79	1600
FW_3-6	833	119	714	0.71	9500
FW_3-7	835	119	716	0.71	14100
FW_3-2	835	119	716	0.71	47600
FW_3-18	814	116	698	0.69	2000100 +
FW_3-13	786	121	665	0.67	2000100 +
FW_3-1	776	119	657	0.66	8400
FW_3-8	783	120	663	0.66	206700
FW_3-4	750	118	632	0.64	200
FW_3-19	722	120	602	0.61	2000100 +
FW_3-10	707	118	587	0.60	2000100 +
FW_3-11	698	116	582	0.59	2000100 +

Average fexural strength fr = 1181 psi (from table no 3.)

+ Beams crossed 2 million cycles

TABLE 4. FATIGUE TEST RESULTS
FOR MIX FW_4

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		DYNAMIC LOAD	
			WIDTH	DEPTH	MAX. LBS.	MIN. LBS.
FW_4-1	5-02-90		3.150	4.007	2875	479
FW_4-2	5-01-90		3.057	4.023	2636	479
FW_4-3	4-29-90		3.043	4.020	2636	479
FW_4-4	4-28-90		3.003	4.000	3115	479
FW_4-5	4-27-90		3.013	4.033	3354	479
FW_4-6	4-22-90		3.035	4.003	3834	479
FW_4-7	4-30-90		3.000	4.003	2636	479
FW_4-9	4-29-90		3.030	4.013	2875	479
FW_4-11	4-28-90		3.037	4.003	3115	479
FW_4-12	4-22-90		3.037	4.007	3834	479
FW_4-14	4-22-90		3.013	4.007	4313	479
FW_4-15	4-28-90		3.043	4.020	2875	479
FW_4-17	4-23-90		3.032	4.020	3354	479
FW_4-18	4-28-90		3.020	4.000	2875	479
FW_4-19	4-22-90		3.015	4.000	4313	479
FW_4-20	4-27-90		3.017	4.043	3354	479

TABLE 4A. FATIGUE TEST RESULTS

FOR MIX -- FW_4

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_4-19	1073	119	954	0.92	1200
FW_4-14	1070	119	951	0.91	4
FW_4-6	946	118	828	0.81	1400
FW_4-12	943	118	825	0.81	4400
FW_4-5	821	117	704	0.70	374100
FW_4-17	821	117	704	0.70	1807900
FW_4-20	816	117	699	0.69	2000100 +
FW_4-4	778	120	658	0.66	16200
FW_4-11	768	118	650	0.65	64700
FW_4-18	714	119	595	0.61	2000100 +
FW_4-15	702	117	585	0.60	49200
FW_4-9	707	118	589	0.60	130100
FW_4-1	682	114	568	0.58	81800
FW_4-7	658	119	539	0.56	2000100 +
FW_4-3	643	117	526	0.55	2000100 +
FW_4-2	639	116	523	0.54	2000100 +

Average fexural strength fr = 1171 psi (from table no 4.)

+ Beams crossed 2 million cycles

TABLE 5. FATIGUE TEST RESULTS
FOR MIX FW_5

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		DYNAMIC LOAD	
			WIDTH	DEPTH	MAX. LBS.	MIN. LBS.
FW_5-2	5-02-90		3.057	4.007	3358	480
FW_5-3	4-29-90		3.043	4.022	3838	480
FW_5-4	4-29-90		3.015	3.995	3838	480
FW_5-6	5-04-90		3.072	3.997	3118	480
FW_5-7	5-06-90		3.043	4.005	3118	480
FW_5-8	4-29-90		3.017	4.010	4317	480
FW_5-9	4-29-90		3.045	4.003	4317	480
FW_5-10	5-07-90		3.050	4.007	3598	480
FW_5-11	5-03-90		3.010	4.000	3358	480
FW_5-12	5-08-90		3.060	4.007	3598	480
FW_5-13	5-02-90		3.003	4.003	3358	480
FW_5-14	5-08-90		3.013	4.017	3358	480
FW_5-16	5-07-90		3.037	4.012	3598	480
FW_5-17	5-05-90		3.067	4.015	3118	480
FW_5-18	5-04-90		3.015	4.000	3598	480
FW_5-19	5-04-90		3.033	4.032	3358	480

TABLE 5A. FATIGUE TEST RESULTS

FOR MIX -- FW_5

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_5-8	1068	119	949	0.90	4
FW_5-9	1062	118	944	0.89	4000
FW_5-4	957	120	837	0.81	17600
FW_5-3	936	117	819	0.79	21900
FW_5-18	895	119	776	0.76	65500
FW_5-16	883	118	765	0.75	8100
FW_5-10	882	118	764	0.74	2000100 +
FW_5-12	879	117	762	0.74	43500
FW_5-13	837	120	717	0.71	2000100 +
FW_5-11	837	108	717	0.71	2000100 +
FW_5-14	829	118	711	0.70	56400
FW_5-19	817	117	700	0.69	29600
FW_5-2	821	117	704	0.69	31800
FW_5-7	767	118	649	0.65	2000100 +
FW_5-6	762	117	645	0.64	2000100 +
FW_5-17	757	117	640	0.64	2000100 +

Average fexural strength fr = 1185 psi (from table no 5.)

+ Beams crossed 2 million cycles

TABLE 6. FATIGUE TEST RESULTS
FOR MIX FW_6

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		DYNAMIC LOAD	
			WIDTH	DEPTH	MAX. LBS.	MIN. LBS.
FW_6-2	5-14-90		3.035	4.000	4181	465
FW_6-3	5-09-90		3.050	4.013	3020	465
FW_6-4	5-14-90		3.007	4.000	3485	465
FW_6-6	5-10-90		3.013	4.010	3020	465
FW_6-7	5-15-90		3.000	4.013	3252	465
FW_6-8	5-14-90		3.023	4.003	3717	465
FW_6-9	5-14-90		3.043	4.040	3485	465
FW_6-11	5-13-90		3.082	4.007	3252	465
FW_6-12	5-14-90		3.050	4.013	3485	465
FW_6-13	5-12-90		3.040	4.010	3252	465
FW_6-14	5-09-90		3.083	4.007	3020	465
FW_6-16	5-13-90		3.053	4.010	3252	465
FW_6-17	5-08-90		3.063	4.000	3020	465
FW_6-18	5-14-90		3.033	4.013	4181	465
FW_6-19	5-11-90		3.053	4.030	3252	465
FW_6-20	5-14-90		3.040	4.043	3717	465

TABLE 6A. FATIGUE TEST RESULTS

FOR MIX -- FW_6

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_6-2	1033	115	918	0.90	31800
FW_6-18	1027	114	913	0.90	2000100 +
FW_6-8	921	115	806	0.80	4
FW_6-20	898	112	786	0.78	29600
FW_6-4	869	116	753	0.76	17600
FW_6-9	842	112	730	0.74	4000
FW_6-12	851	114	737	0.74	2000100 +
FW_6-7	808	115	693	0.71	2000100 +
FW_6-16	795	114	681	0.69	56400
FW_6-13	798	114	684	0.70	43500
FW_6-19	787	113	674	0.69	65500
FW_6-11	789	113	676	0.69	2000100 +
FW_6-17	739	114	625	0.65	8100
FW_6-6	748	115	633	0.65	2000100 +
FW_6-3	738	114	624	0.64	21900
FW_6-14	732	113	619	0.64	2000100 +

Average fexural strength fr = 1145 psi (from table no 6.)

+ Beams crossed 2 million cycles

TABLE 7. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MIX FW_1

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WIDTH	DEPTH	MODULUS OF RUPTURE
FW_1-15	4-05-90		3.068	4.022	1035
FW_1-20	4-05-90		3.035	4.019	1210
FW_1-19	4-05-90		3.031	3.998	1150
			MEAN = 1135 S.D = 88.93 C.V = 7.8		

RESULTS OF BEAMS TESTED IN FLEXURE AFTER FATIGUE

SPECIMEN NO.	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WDTHH (IN)	DEPTH (IN)	MODULUS OF RUPTURE (PSI)
+ FW_1-3	4-12-90		3.103	4.003	1150
+ FW_1-1	4-12-90		3.119	4.025	1166
+ FW_1-8	4-12-90		3.106	3.998	1158
+ FW_1-12	4-12-90		3.065	4.020	1167
+ FW_1-18	4-12-909		3.043	4.001	1085
+ FW_1-16	4-12-90		3.056	4.013	1115
+ FW_1-13	4-12-90		3.046	3.998	835
			MEAN = 1100 S.D = 119.23 C.V = 10.8		

+ Beams crossed 2 million cycles.

TABLE 8. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MI[illegible] FW_2

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WIDTH	DEPTH	MODULUS OF RUPTURE
FW_2-3	4-12-90		3.050	4.003	1200
FW_2-7	4-12-90		3.090	4.000	1164
FW_2-9	4-12-90		3.051	4.015	1182
FW_2-13	4-12-90		3.006	4.012	1265
			MEAN = 1205 S.D = 44.03 C.V = 3.7		

RESULTS OF BEAMS TESTED IN FLEXURE AFTER FATIGUE

SPECIMEN NO.	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WDTHH (IN)	DEPTH (IN)	MODULUS OF RUPTURE (PSI)
+ FW_2-5	4-18-90		2.983	4.012	1085
+ FW_2-6	4-18-90		2.973	4.025	1136
+ FW_2-12	4-18-90		3.003	4.027	1070
+ FW_2-16	4-18-90		3.067	4.000	1238
+ FW_2-18	4-18-90		3.023	4.013	1200
			MEAN = 1150 S.D = 72.42 C.V = 6.3		

+ Beams crossed 2 million cycles.

TABLE 9. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MIX FW_3

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WIDTH	DEPTH	MODULUS OF RUPTURE
FW_3-5	4-18-90		3.050	4.018	1187
FW_3-14	4-18-90		3.063	4.033	1230
FW_3-15	4-18-90		3.083	4.025	1160
FW_3-20	4-18-90		3.023	4.030	1147
			MEAN = 1181 S.D = 36.70 C.V = 3.1		

RESULTS OF BEAMS TESTED IN FLEXURE AFTER FATIGUE

SPECIMEN NO.	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WDTHH (IN)	DEPTH (IN)	MODULUS OF RUPTURE (PSI)
+ FW_3-10	4-22-90		3.090	4.030	1146
+ FW_3-11	4-22-90		3.095	4.003	1230
+ FW_3-13	4-22-90		3.062	3.973	1327
+ FW_3-19	4-22-90		3.035	4.000	1220
+ FW_3-18	4-27-90		3.060	4.020	1243 .
			MEAN = 1233 S.D = 64.58 C.V = 5.2		

+ Beams crossed 2 million cycles.

TABLE 10. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MIX FW_4

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WIDTH	DEPTH	MODULUS OF RUPTURE
FW_4-8	4-22-90		3.023	4.050	1220
FW_4-10	4-22-90		3.060	4.010	1105
FW_4-13	4-22-90		3.056	3.993	1099
FW_4-16	4-22-90		3.046	4.017	1260
			MEAN = 1171 S.D = 81.37 C.V = 6.9		

RESULTS OF BEAMS TESTED IN FLEXURE AFTER FATIGUE

SPECIMEN NO.	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WDTHH (IN)	DEPTH (IN)	MODULUS OF RUPTURE (PSI)
+ FW_4-2	5-05-90		3.057	4.023	1100
+ FW_4-3	5-05-90		3.043	4.020	1180
+ FW_4-7	5-05-90		3.000	4.003	1145
+ FW_4-18	5-05-90		3.020	4.000	1120
+ FW_4-20	5-05-90		3.017	4.043	1213
			MEAN = 1155 S.D = 45.50 C.V = 3.9		

+ Beams crossed 2 million cycles.

TABLE 11. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MIX FW_5

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WIDTH	DEPTH	MODULUS OF RUPTURE
FW_5-1	4-29-90		3.050	4.000	1198
FW_5-5	4-29-90		3.017	4.000	1230
FW_5-15	4-29-90		3.017	4.013	1158
FW_5-20	4-29-90		3.053	3.997	1154
			MEAN = 1185 S.D = 35.98 C.V = 3.04		

RESULTS OF BEAMS TESTED IN FLEXURE AFTER FATIGUE

SPECIMEN NO.	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WDTHH (IN)	DEPTH (IN)	MODULUS OF RUPTURE (PSI)
+ FW_5-6	5-11-90		3.072	3.997	1280
+ FW_5-7	5-11-90		3.043	4.005	1266
+ FW_5-10	5-11-90		3.050	4.007	1250
+ FW_5-11	5-11-90		3.010	4.000	1248
+ FW_5-13	5-11-90		3.003	4.003	1385
+ FW5-17	5-11-90		3.067	4.015	1213
			MEAN = 1275 S.D = 58.98 C.V = 4.6		

+ Beams crossed 2 million cycles.

TABLE 12. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MIX FW_6

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WIDTH	DEPTH	MODULUS OF RUPTURE
FW_6-1	5-08-90		3.015	4.010	1055
FW_6-5	5-08-90		3.010	4.025	1249
FW_6-10	5-08-90		3.032	4.013	1100
FW_6-15	5-08-90		3.067	4.000	1170
			MEAN = 1145 S.D = 84.77 C.V = 7.4		

RESULTS OF BEAMS TESTED IN FLEXURE AFTER FATIGUE

SPECIMEN NO.	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION WIDTH (IN)	DEPTH (IN)	MODULUS OF RUPTURE (PSI)
+ FW_6-3	5-16-90		3.050	4.013	1163
+ FW_6-6	5-16-90		3.013	4.010	1281
+ FW_6-13	5-16-90		3.040	4.010	1310
+ FW_6-16	5-16-90		3.053	4.010	1302
+ FW_6-17	5-16-90		3.063	4.000	1310
+ FW6-19	5-16-90		3.053	4.030	1258
			MEAN = 1275 S.D = 56.45 C.V = 4.4		

+ Beams crossed 2 million cycles.

TABLE 13. FATIGUE TEST RESULTS

FOR MIX -- FW

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_3-3	1083	120	963	0.92	1100
FW_4-19	1073	119	954	0.91	1200
FW_4-14	1070	119	951	0.91	4
FW_5-8	1068	119	949	0.91	4
FW_5-9	1062	118	944	0.90	5
FW_3-9	1054	117	937	0.89	5
FW_6-2	1033	115	918	0.88	31800
FW_6-18	1027	114	913	0.87	2000100 +
FW_2-11	973	242	731	0.83	5
FW_2-14	973	242	731	0.83	6400
FW_2-10	960	240	720	0.82	2
FW_5-3	963	117	819	0.82	21900
FW_5-4	957	120	837	0.81	17600
FW_3-17	957	120	837	0.81	1046500
FW_4-6	946	118	828	0.81	1400
FW_3-16	948	119	829	0.81	6900
FW_4-12	943	118	825	0.80	4400

+ Beams crossed 2 million cycles

TABLE 13A. FATIGUE TEST RESULTS

FOR MIX -- FW

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_3-12	939	118	821	0.80	1600
FW_6-18	921	115	806	0.78	4
FW_1-7	907	226	681	0.77	3300
FW_2-2	910	188	722	0.77	12300
FW_1-2	902	224	678	0.77	4700
FW_6-20	898	112	786	0.76	29600
FW_5-18	895	119	776	0.76	65500
FW_1-11	893	222	671	0.76	121000
FW_5-16	883	118	765	0.75	8100
FW_5-10	882	118	764	0.75	2000100 +
FW_3-6	883	119	714	0.75	9500
FW_5-12	879	117	762	0.75	43500
FW_6-4	869	116	753	0.74	17600
FW2-8	879	212	667	0.73	900
FW2-15	877	212	665	0.73	52300
FW_6-9	842	112	730	0.72	4000
FW_6-12	851	114	737	0.72	2000100 +
FW_1-17	835	201	634	0.71	1046500
FW_5-13	837	120	717	0.71	2000100 +
FW_5-11	837	108	717	0.69	2000100 +

+ Beams crossed 2 million cycles

TABLE 13B. FATIGUE TEST RESULTS

FOR MIX -- FW

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_3-7	835	119	716	0.71	14100
FW_3-2	835	119	716	0.71	47600
FW_1-6	820	201	619	0.70	4500
FW_5-14	829	118	711	0.70	56400
FW_4-5	821	117	704	0.70	374100
FW_4-17	821	117	704	0.70	1807900
FW_2-17	827	196	631	0.70	14900
FW_2-19	827	196	631	0.70	43400
FW_1-14	810	201	609	0.69	6400
FW_6-7	808	115	693	0.69	2000100 +
FW_5-19	817	117	700	0.69	29600
FW_5-2	821	117	704	0.69	31800
FW_3-18	814	116	698	0.69	2000100 +
FW_4-20	816	117	699	0.69	2000100 +
FW_6-13	798	114	684	0.68	43500
FW_6-16	795	114	681	0.68	56400
FW_2-20	803	118	615	0.68	9100

+ Beams crossed 2 million cycles

TABLE 13C. FATIGUE TEST RESULTS

FOR MIX -- FW

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_6-19	787	113	674	0.67	65500
FW_6-11	789	113	676	0.67	2000100 +
FW_3-13	786	121	665	0.67	2000100 +
FW_2-12	789	182	607	0.67	2000100 +
FW_1-4	779	185	594	0.66	62300
FW_1-16	775	182	593	0.66	2000100 +
FW_3-1	776	119	657	0.66	8400
FW_3-8	783	120	663	0.66	206700
FW_4-4	778	120	658	0.66	16200
FW_1-12	766	180	586	0.65	2000100 +
FW_1-3	765	180	585	0.65	2000100 +
FW_5-7	767	118	649	0.65	2000100 +
FW_4-11	768	118	650	0.65	64700
FW_2-4	770	117	593	0.65	79400
FW_5-6	762	117	645	0.65	2000100 +
FW_5-17	757	117	640	0.64	2000100 +
FW_3-4	750	118	632	0.64	200

+ Beams crossed 2 million cycles

TABLE 13D. FATIGUE TEST RESULTS

FOR MIX -- FW

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_2-5	755	169	586	0.64	2000100 +
FW_2-6	752	171	581	0.64	2000100 +
FW_1-9	736	170	566	0.63	30500
FW_1-13	743	172	571	0.63	2000100 +
FW_1-18	738	169	569	0.63	2000100 +
FW_6-17	739	114	625	0.63	8100
FW_6-6	748	115	633	0.63	2000100 +
FW_6-3	738	114	624	0.63	21900
FW_2-18	744	167	577	0.63	2000100 +
FW_1-8	724	167	557	0.62	2000100 +
FW_6-14	732	113	619	0.62	2000100 +
FW_2-1	730	164	566	0.62	77200
FW_1-1	711	164	547	0.61	2000100 +
FW_3-19	722	120	602	0.61	2000100 +
FW_4-18	714	119	595	0.61	2000100 +
FW_4-15	702	117	585	0.60	49200
FW_4-9	707	118	589	0.60	130100

+ Beams crossed 2 million cycles

TABLE 13E. FATIGUE TEST RESULTS

FOR MIX -- FW

SPE.	MAXI. STRESS	MINI. STRESS	STRESS RANGE	fmax/fr	CYCLES AT FAILURE
FW_3-10	707	118	587	0.60	2000100 +
FW_3-11	698	116	582	0.59	2000100 +
FW_2-16	693	151	542	0.59	2000100 +
FW_4-1	682	114	568	0.58	81800
FW_4-7	658	119	539	0.56	2000100 +
FW_4-3	643	117	526	0.55	2000100 +
FW_4-2	639	116	523	0.54	2000100 +

+ Beams crossed 2 million cycles

TABLE 14. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MIX FW

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		MODULUS OF RUPTURE
			WIDTH	DEPTH	
FW_1-15	4-05-90		3.068	4.022	1035
FW_1-20	4-05-90		3.035	4.019	1210
FW_1-19	4-05-90		3.031	3.998	1150
FW_2-3	4-12-90		3.050	4.003	1200
FW_2-7	4-12-90		3.090	4.000	1164
FW_2-9	4-12-90		3.051	4.015	1182
FW_2-13	4-12-90		3.006	4.012	1265
FW_3-5	4-18-90		3.050	4.018	1187
FW_3-14	4-18-90		3.063	4.033	1230
FW_3-15	4-18-90		3.083	4.025	1160
FW_3-20	4-18-90		3.023	4.030	1147
FW_4-8	4-22-90		3.023	4.050	1220
FW_4-10	4-22-90		3.060	4.010	1105
FW_4-13	4-22-90		3.056	3.993	1099
FW_4-16	4-22-90		3.046	4.017	1260

TABLE 14a. STATIC FLEXURE TEST RESULTS BEFORE FATIGUE FOR MIX FW

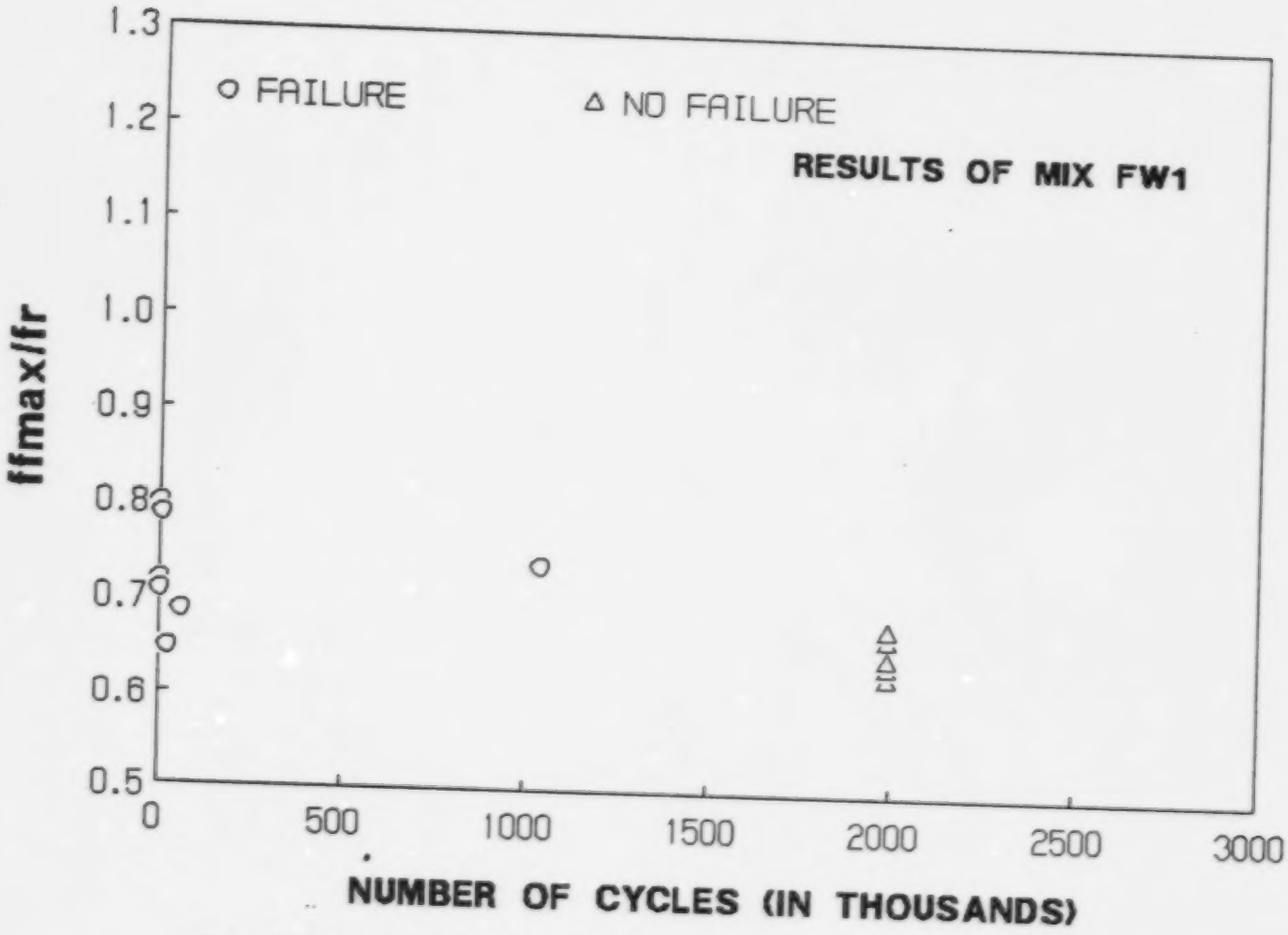
SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		MODULUS OF RUPTURE
			WIDTH	DEPTH	
FW_5-1	4-29-90		3.050	4.000	1198
FW_5-5	4-29-90		3.017	4.000	1230
FW_5-15	4-29-90		3.017	4.013	1158
FW_5-20	4-29-90		3.053	3.997	1154
FW_6-1	5-08-90		3.015	4.010	1055
FW_6-5	5-08-90		3.010	4.025	1249
FW_6-10	5-08-90		3.032	4.013	1100
FW_6-15	5-08-90		3.067	4.000	1170
			MEAN = 1175 S.D = 61.74 C.V = 5.25		

TABLE 15. STATIC FLEXURE TEST RESULTS AFTER FATIGUE FOR MIX FW

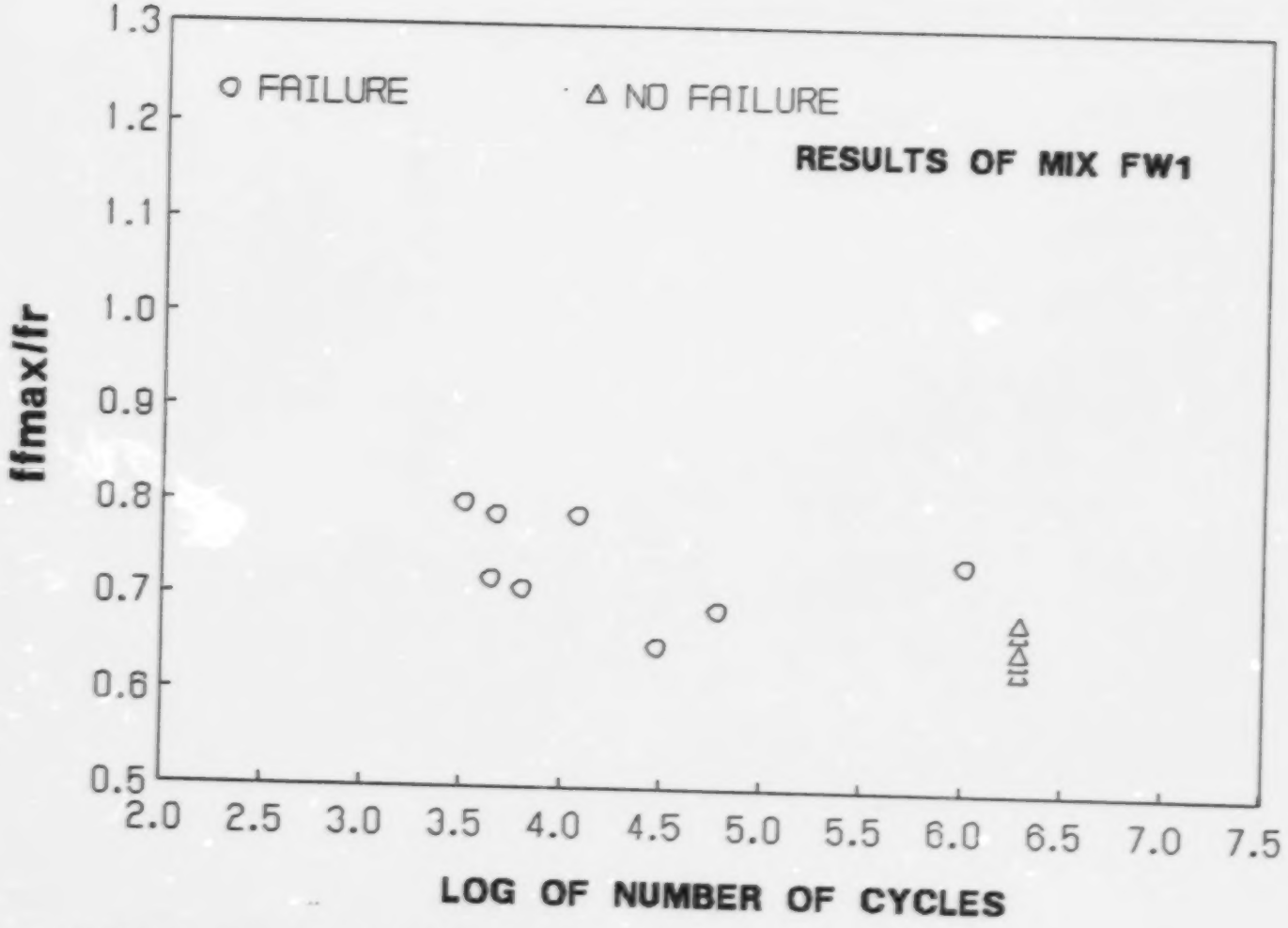
SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		MODULUS OF RUPTURE
			WIDTH	DEPTH	
FW_1-1	4-12-90		3.119	4.025	1166
FW_1-3	4-12-90		3.103	4.003	1150
FW_1-8	4-12-90		3.106	3.998	1158
FW_1-12	4-12-90		3.065	4.020	1167
FW_1-13	4-12-90		3.046	3.998	835
FW_1-16	4-12-90		3.056	4.013	1115
FW_1-18	4-12-90		3.043	4.001	1085
FW_2-5	4-18-90		2.983	4.012	1085
FW_2-6	4-18-90		2.973	4.025	1136
FW_2-12	4-18-90		3.003	4.027	1070
FW_2-16	4-18-90		3.067	4.000	1238
FW_2-18	4-18-90		3.023	4.013	1200
FW_3-10	4-22-90		3.090	4.030	1146
FW_3-11	4-22-90		3.095	4.003	1230
FW_3-13	4-22-90		3.062	3.973	1327
FW_3-18	4-22-90		3.060	4.020	1243
FW_3-19	4-22-90		3.035	4.000	1220

TABLE 15A. STATIC FLEXURE TEST RESULTS AFTER FATIGUE FOR MIX FW

SPECIMEN	DATE OF TESTING	AGE DAYS	DIMENSIONS AT FAILURE SECTION		MODULUS OF RUPTURE
			WIDTH	DEPTH	
FW_4-2	5-05-90		3.057	4.023	1100
FW_4-3	5-05-90		3.043	4.020	1180
FW_4-7	5-05-90		3.000	4.003	1145
FW_4-18	5-05-90		3.020	4.000	1120
FW_4-20	5-05-90		3.017	4.043	1213
FW_5-6	5-11-90		3.072	3.997	1280
FW_5-7	5-11-90		3.043	4.005	1266
FW_5-10	5-11-90		3.050	4.007	1250
FW_5-11	5-11-90		3.010	4.000	1248
FW_5-13	5-11-90		3.003	4.003	1385
FW_5-17	5-11-90		3.067	4.015	1213
FW_6-3	5-16-90		3.050	4.013	1163
FW_6-6	5-16-90		3.013	4.010	1281
FW_6-13	5-16-90		3.040	4.010	1310
FW_6-16	5-16-90		3.053	4.010	1302
FW_6-17	5-16-90		3.063	4.000	1310
FW_6-19	5-16-90		3.053	4.030	1258
			MEAN = 1195		
			S.D = 100.40		
			C.V = 8.40		



NUMBER OF CYCLES Vs. ffmax/fr



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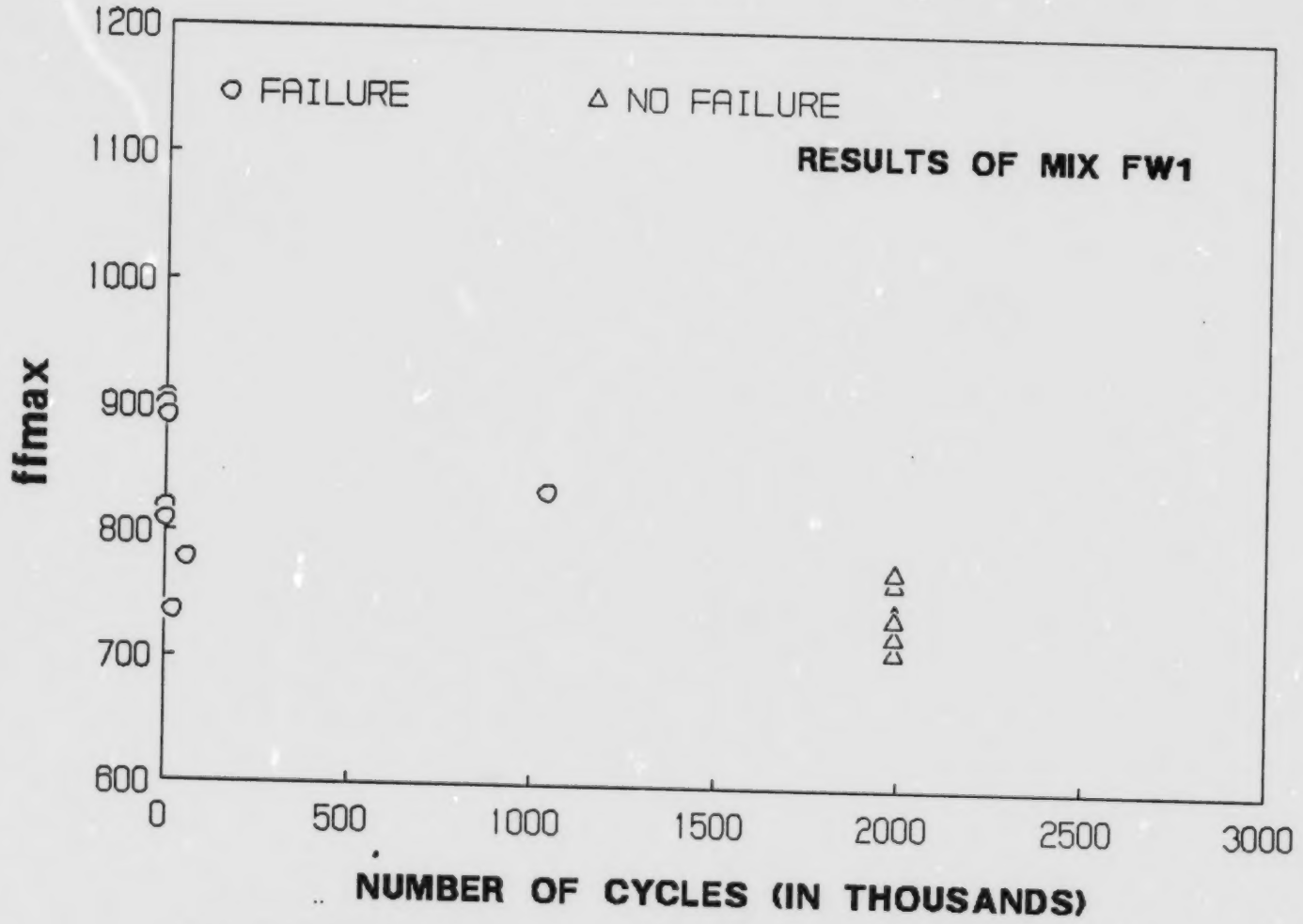

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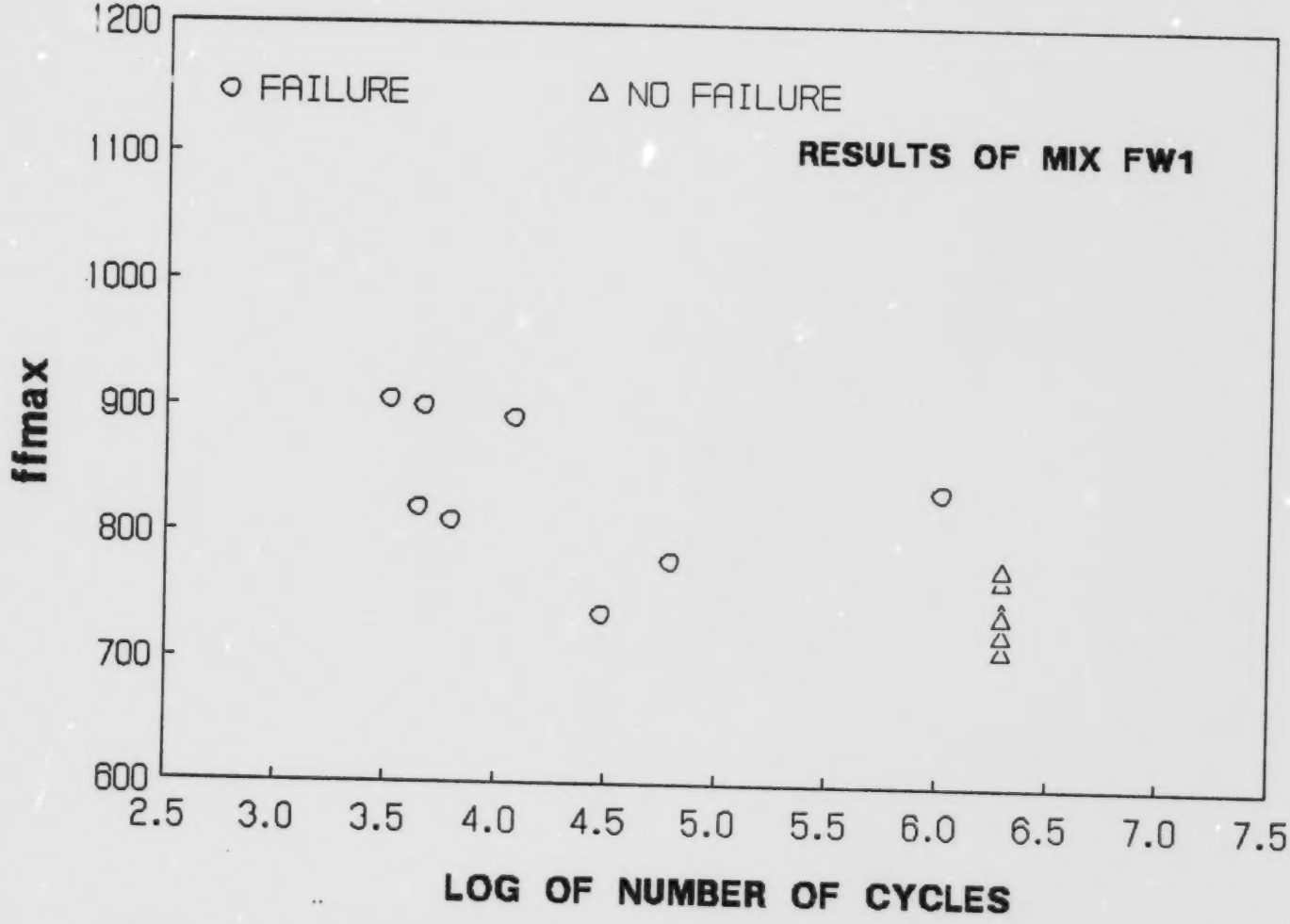

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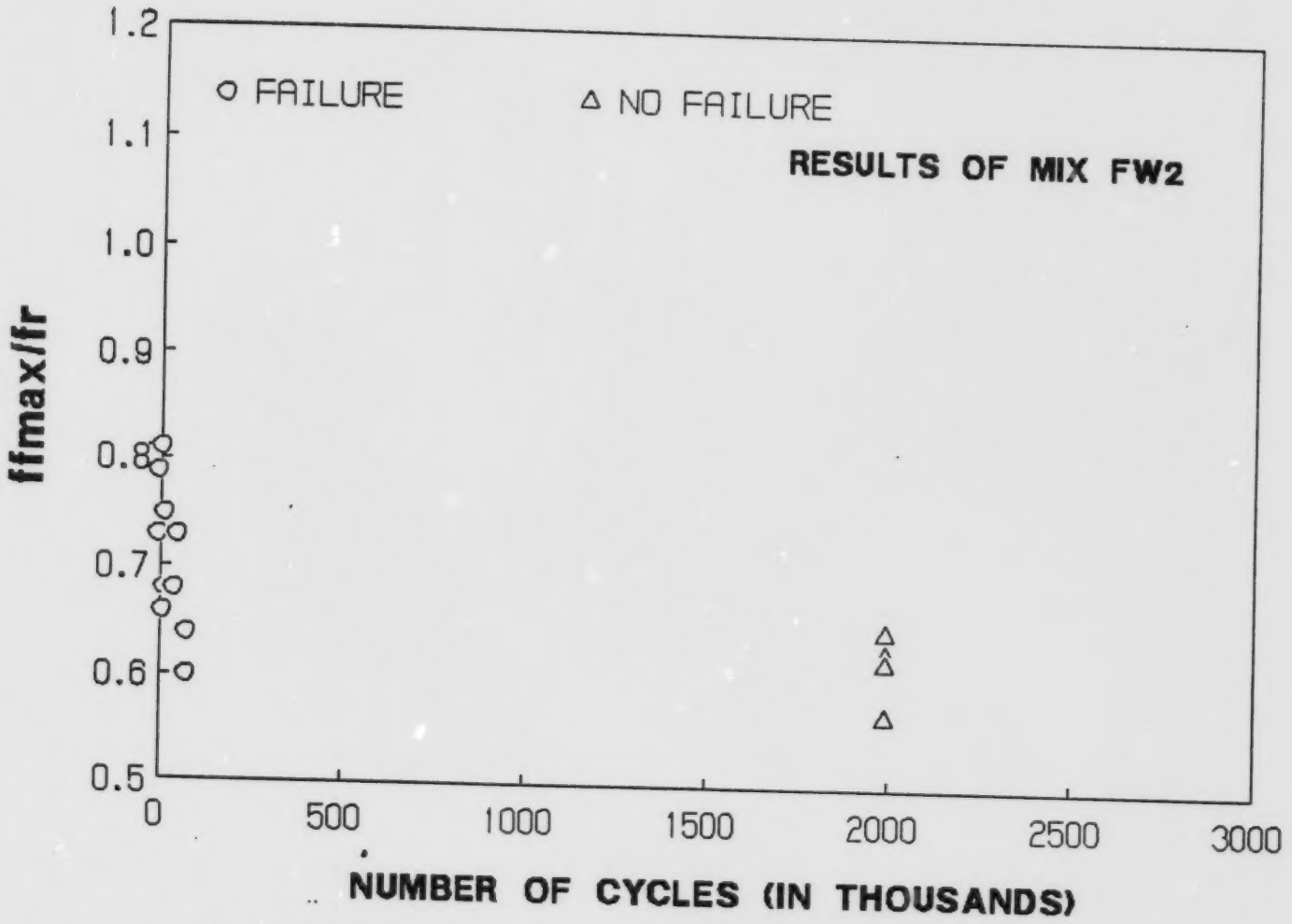

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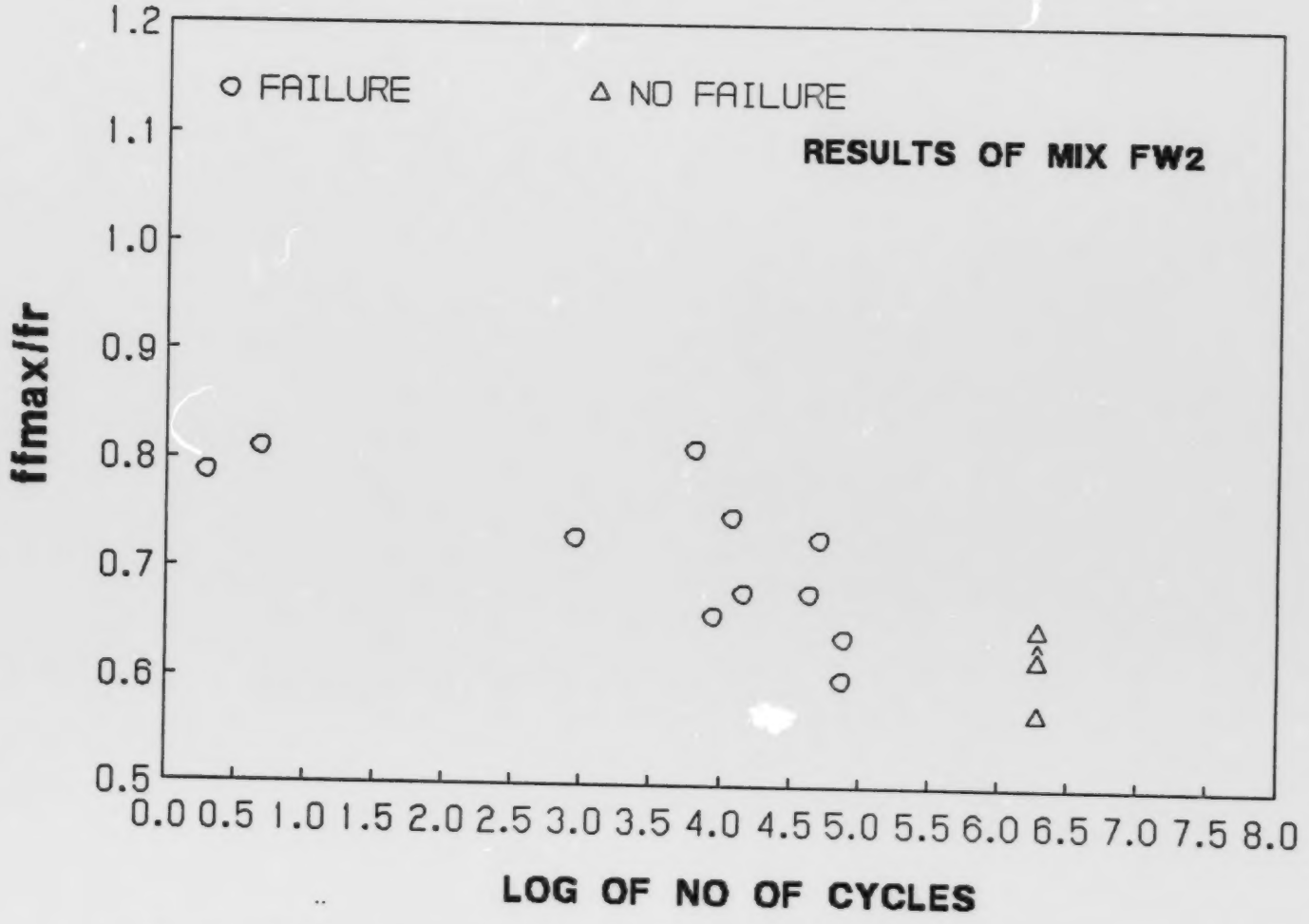

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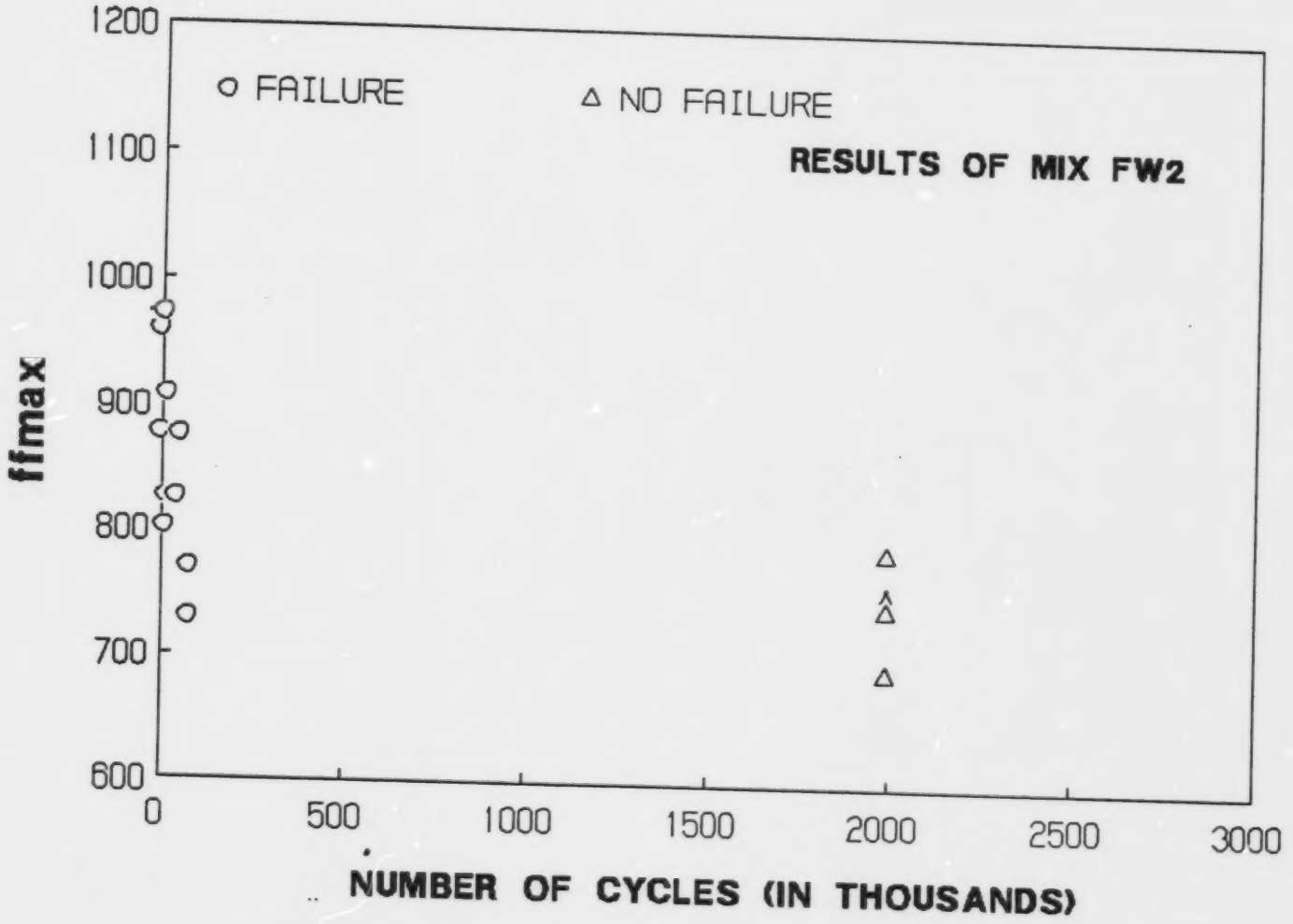

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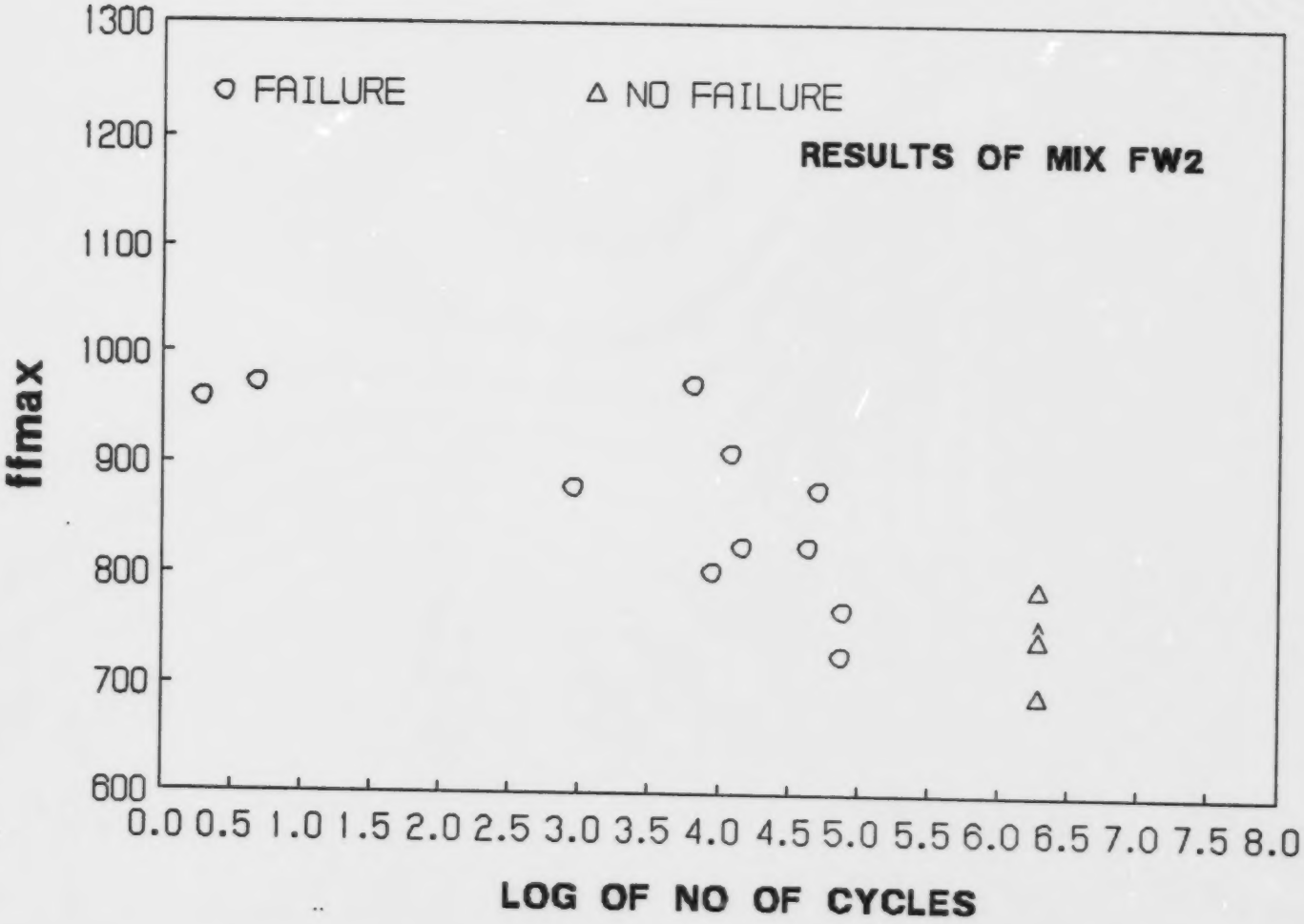

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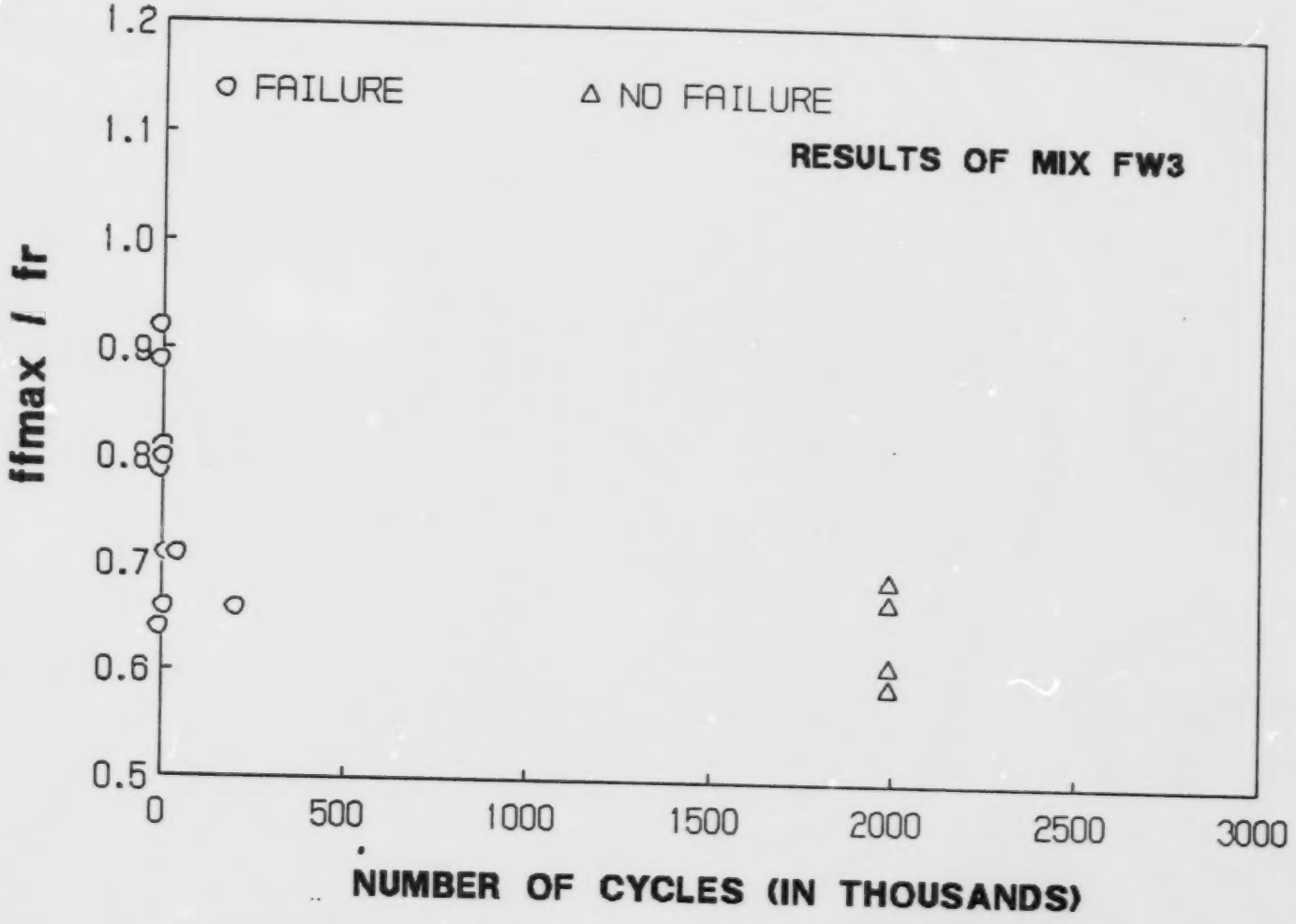

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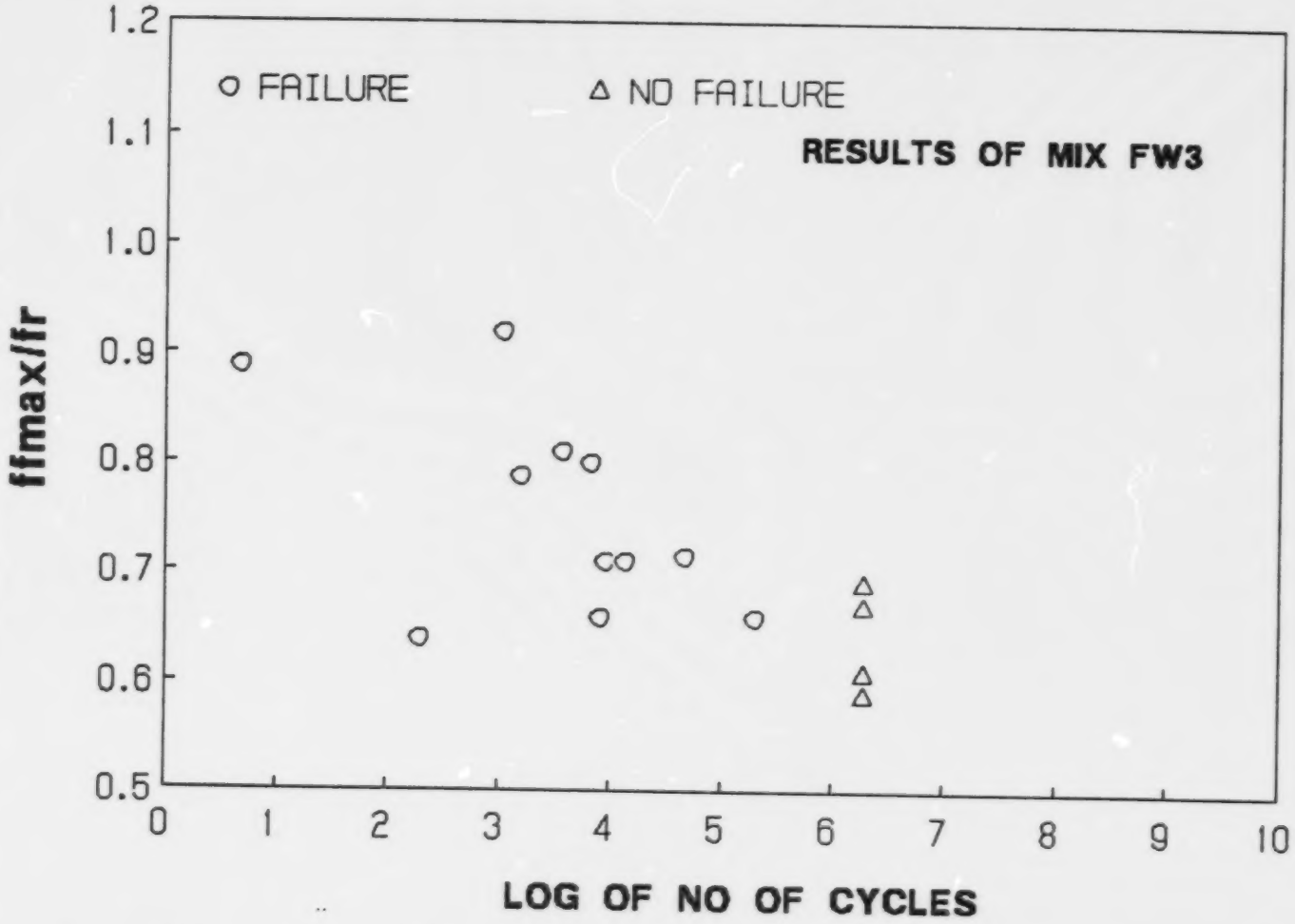

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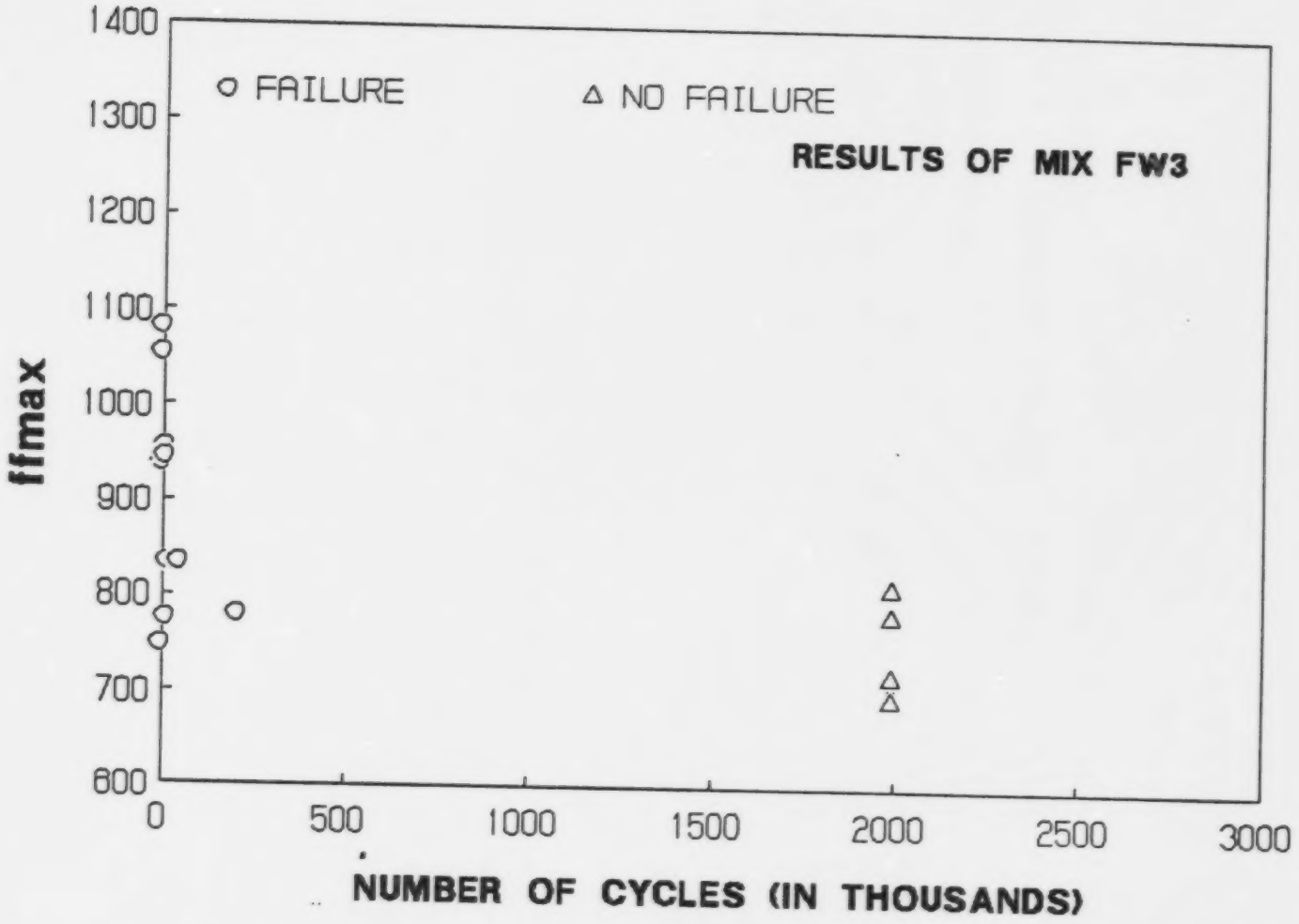

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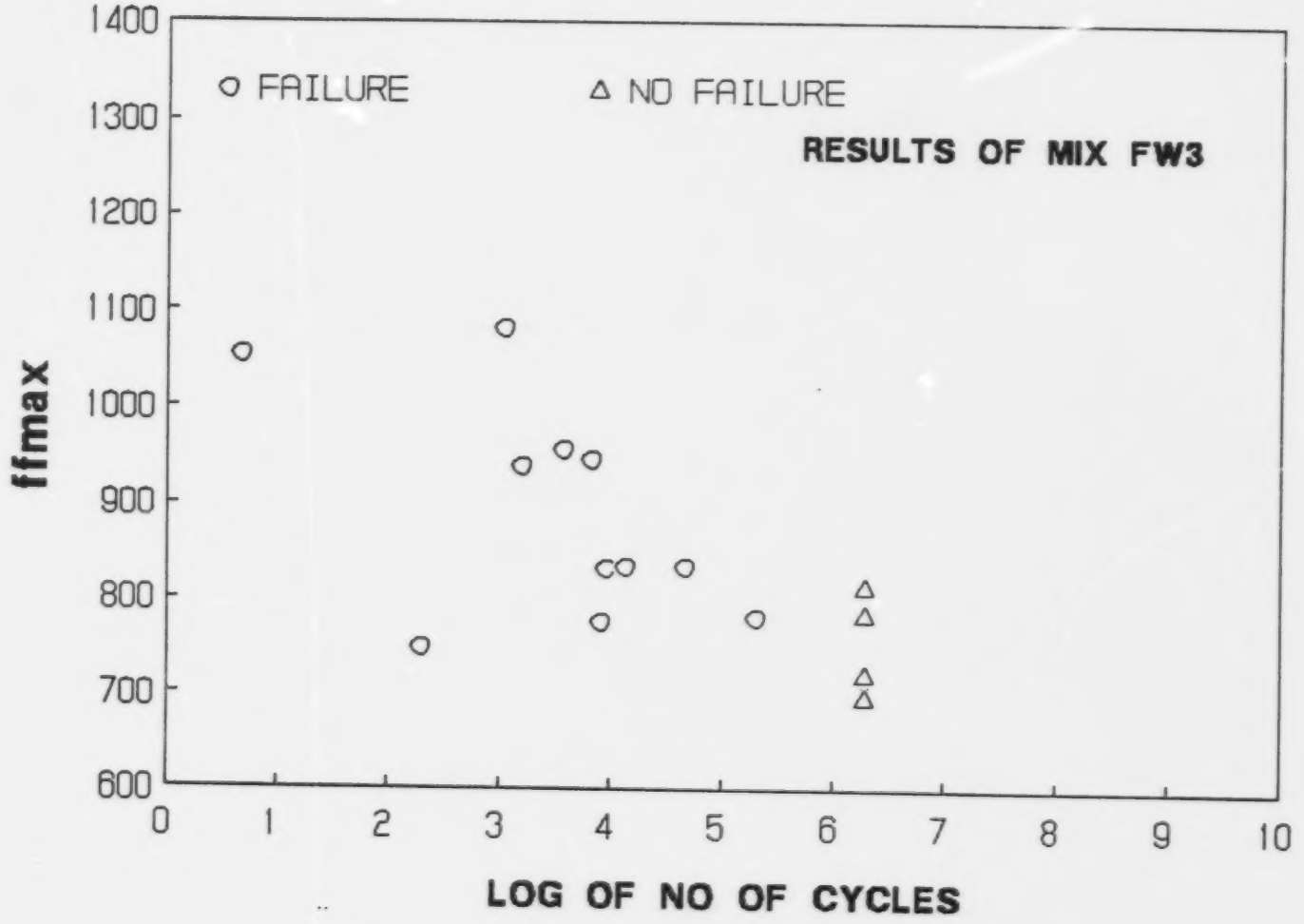

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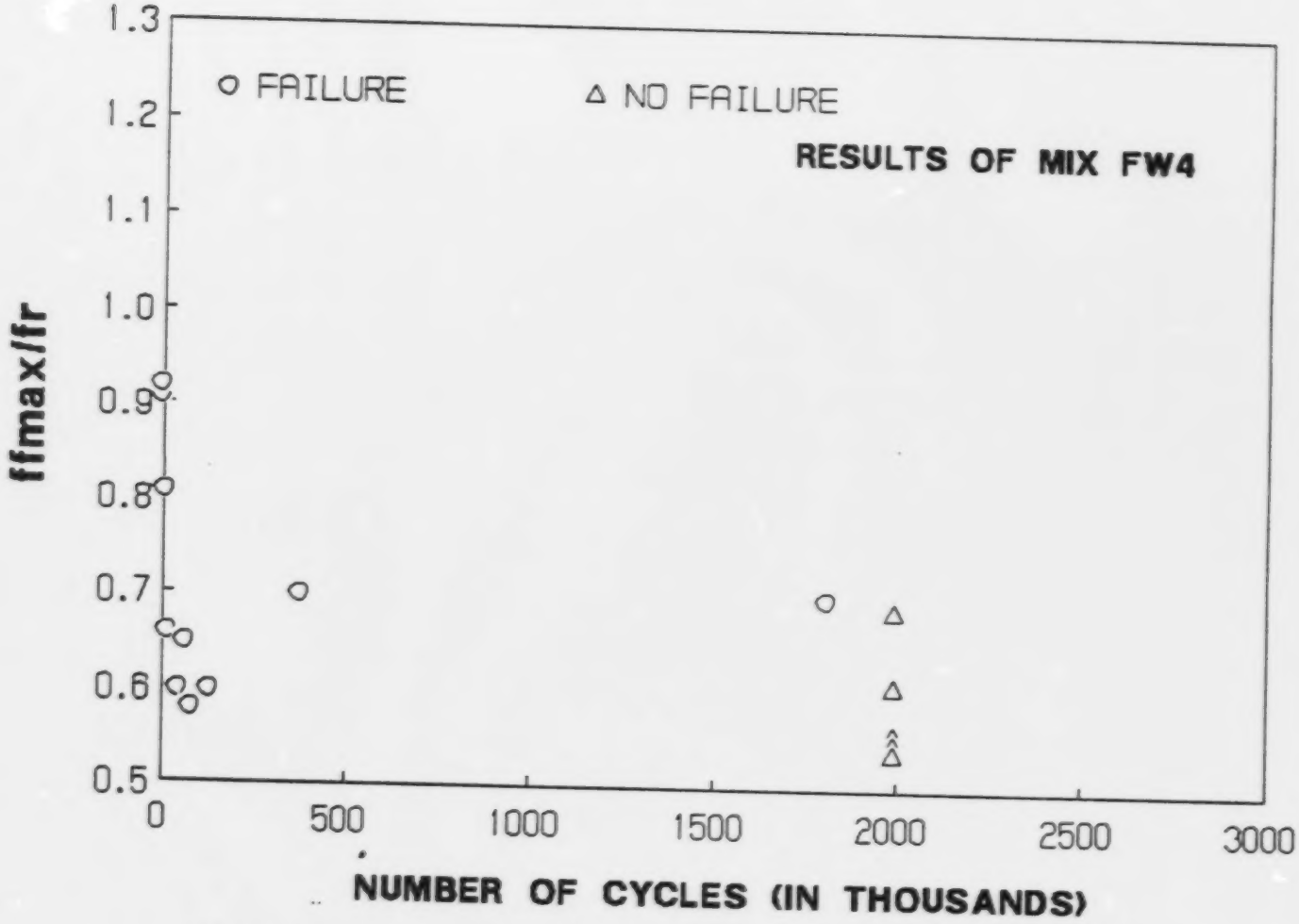

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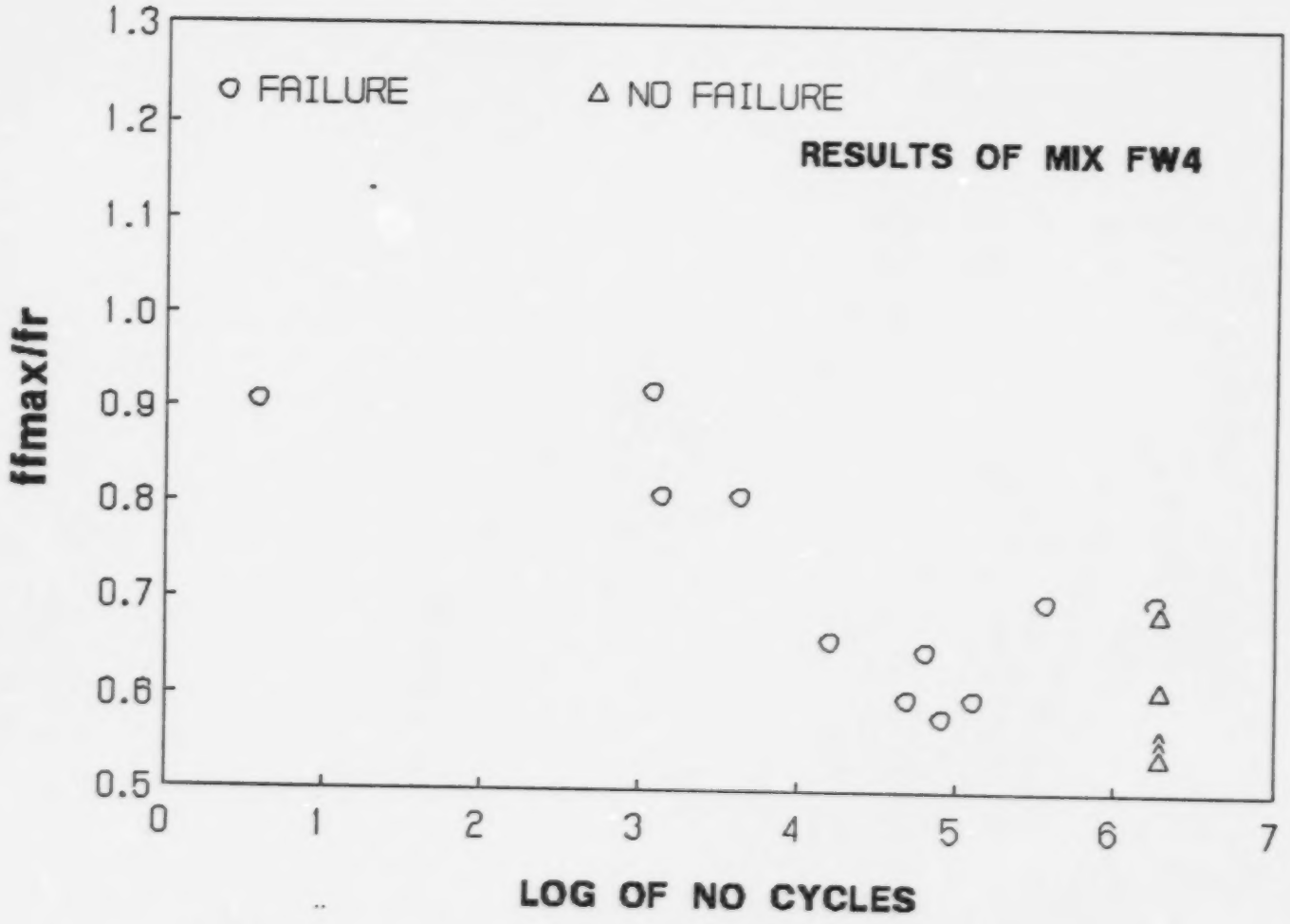

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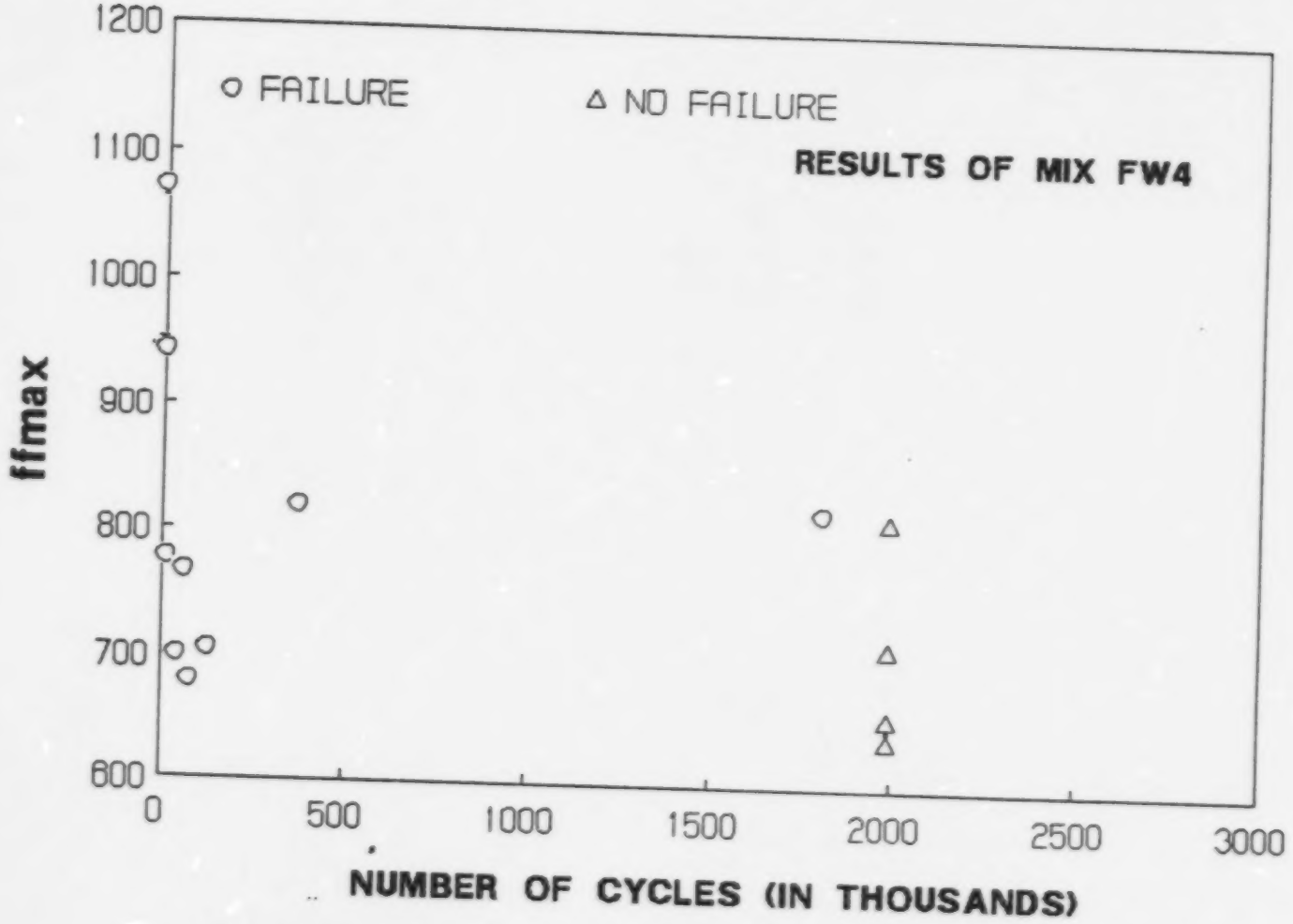

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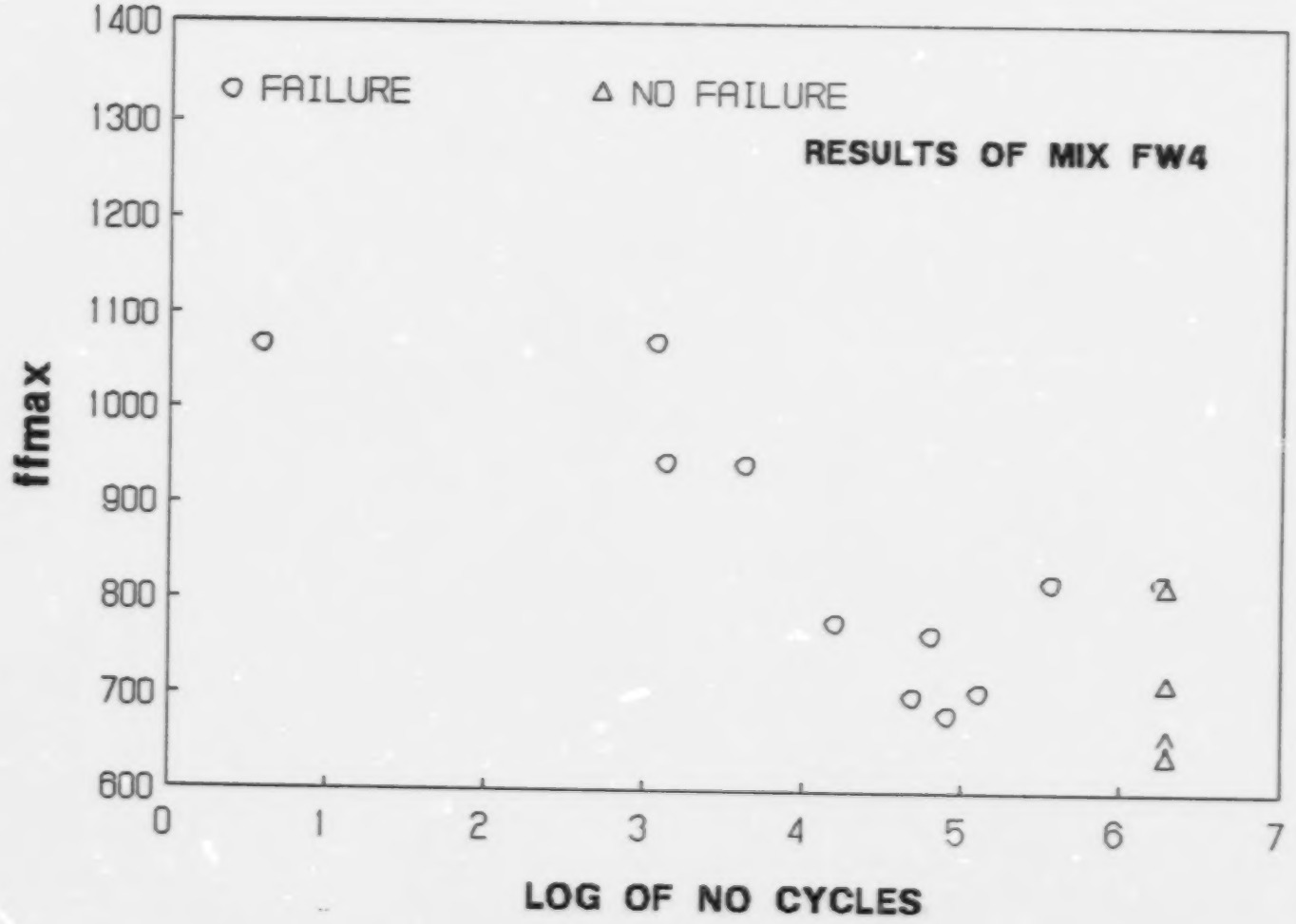

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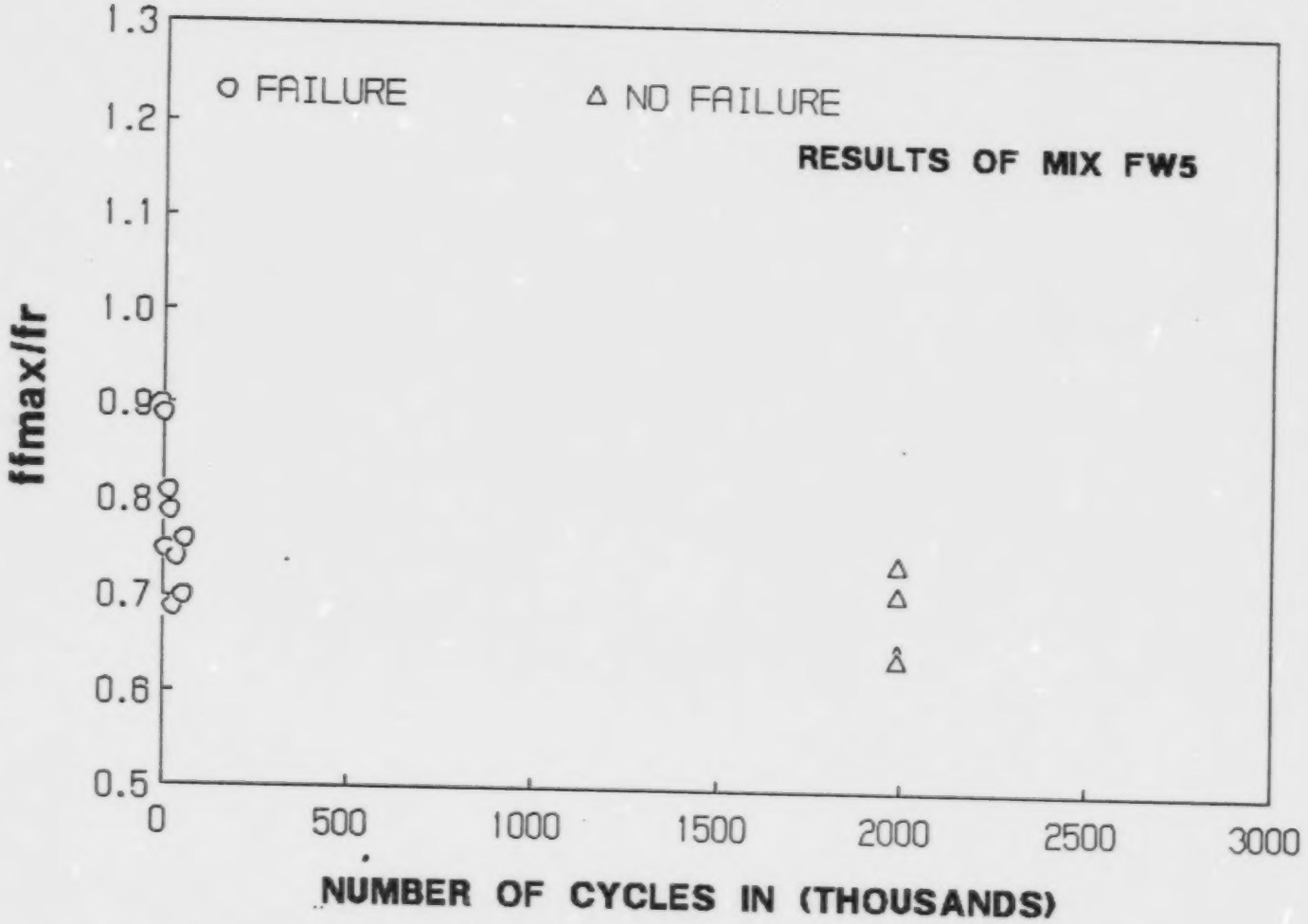

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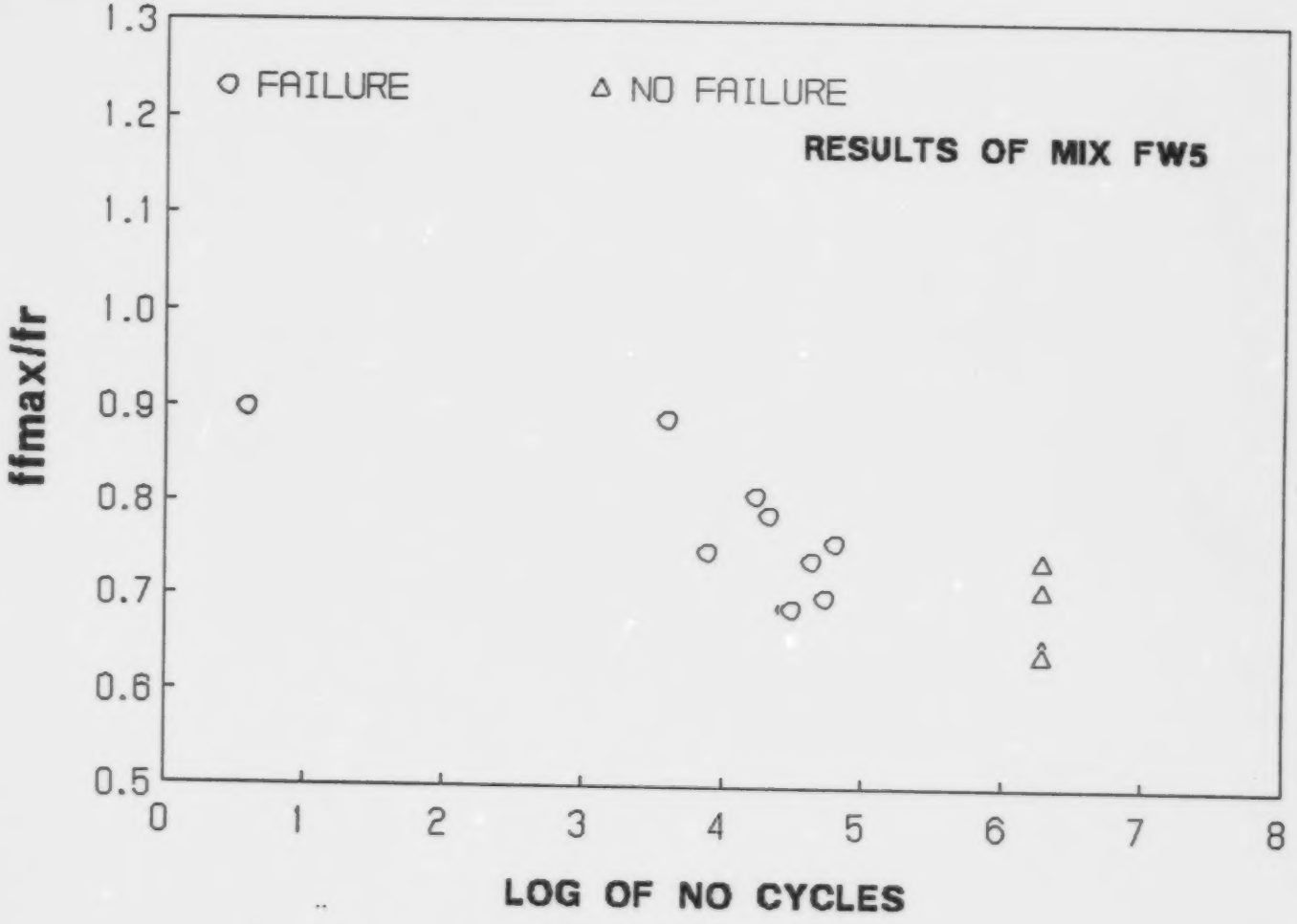

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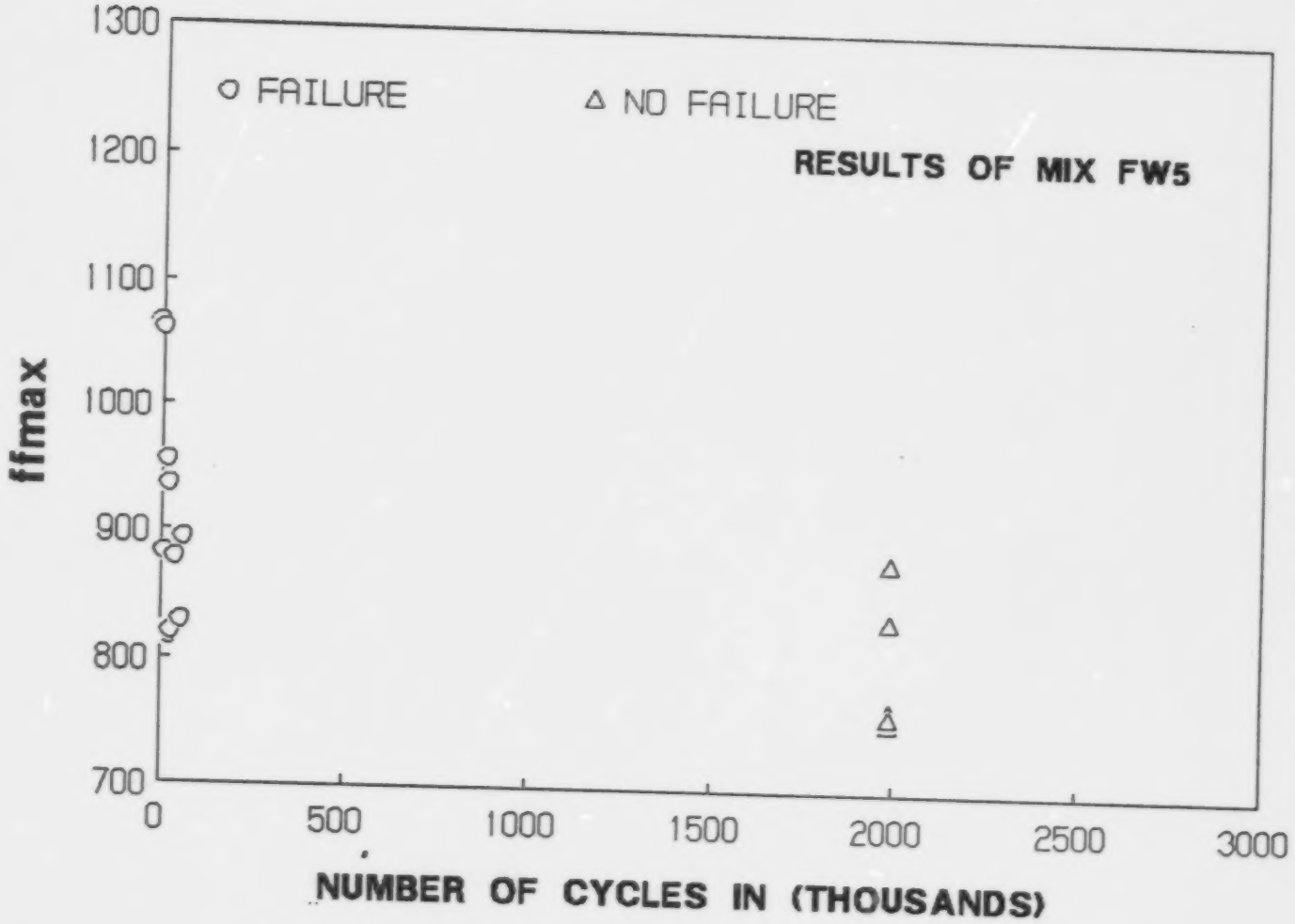

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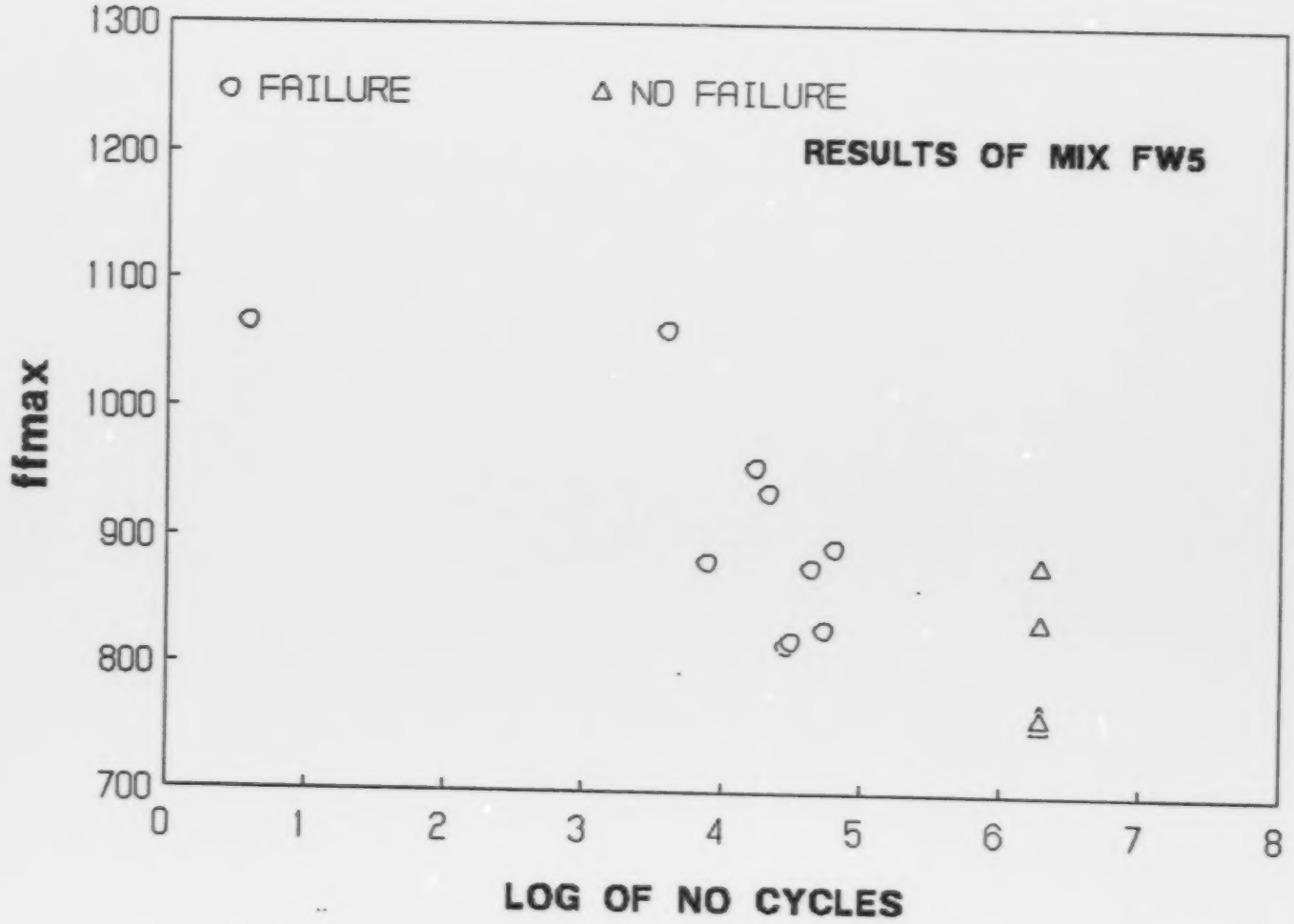

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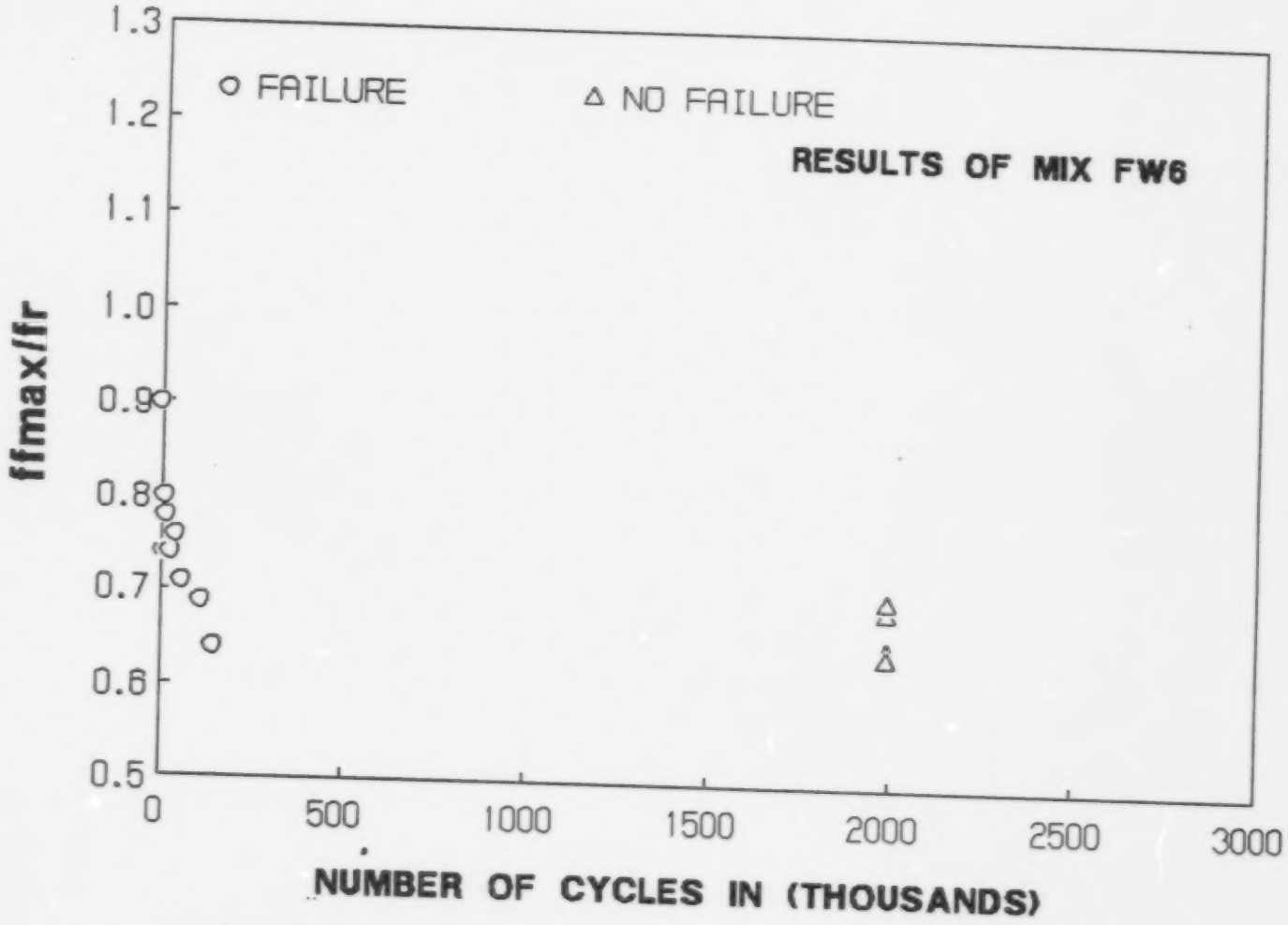

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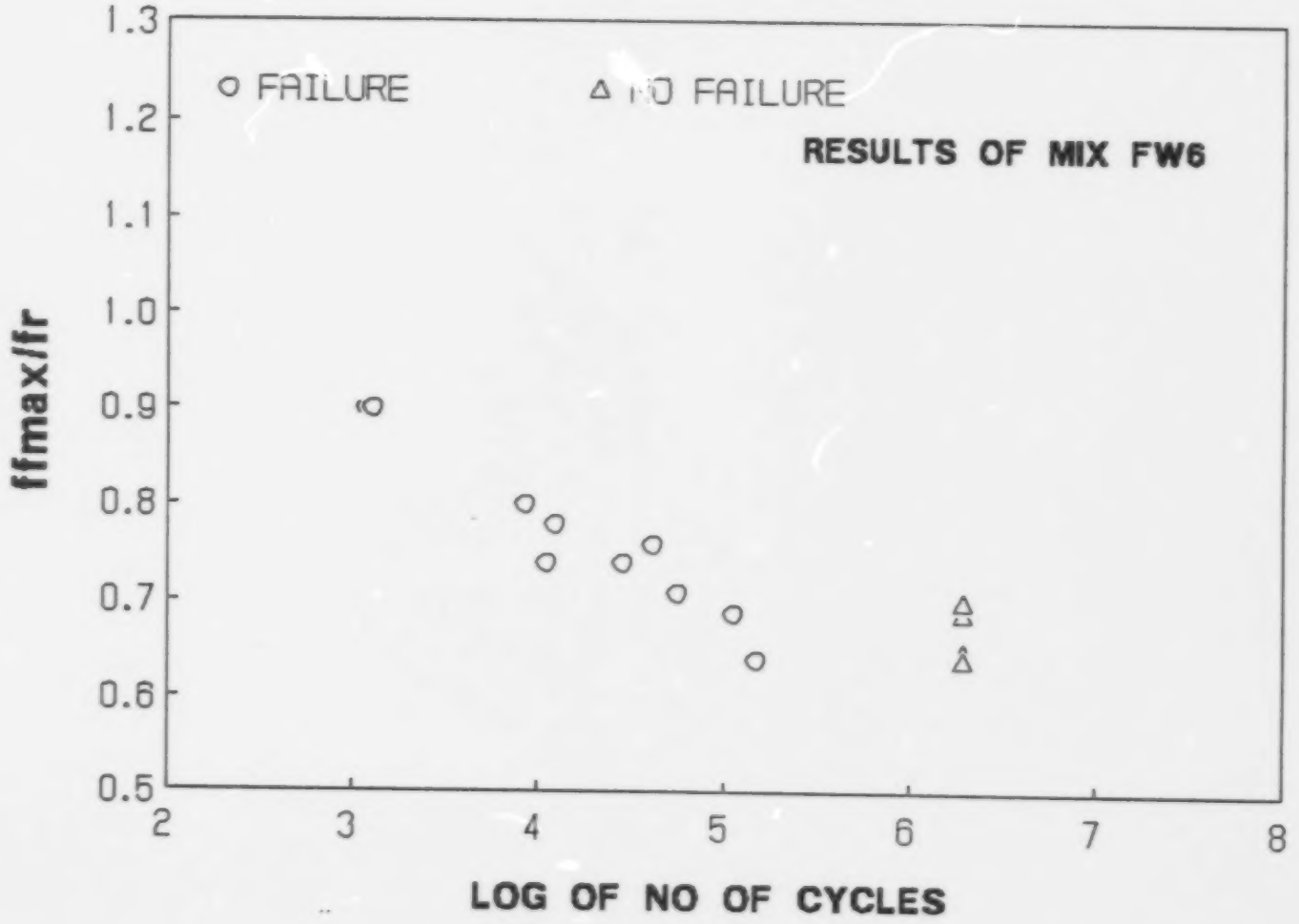

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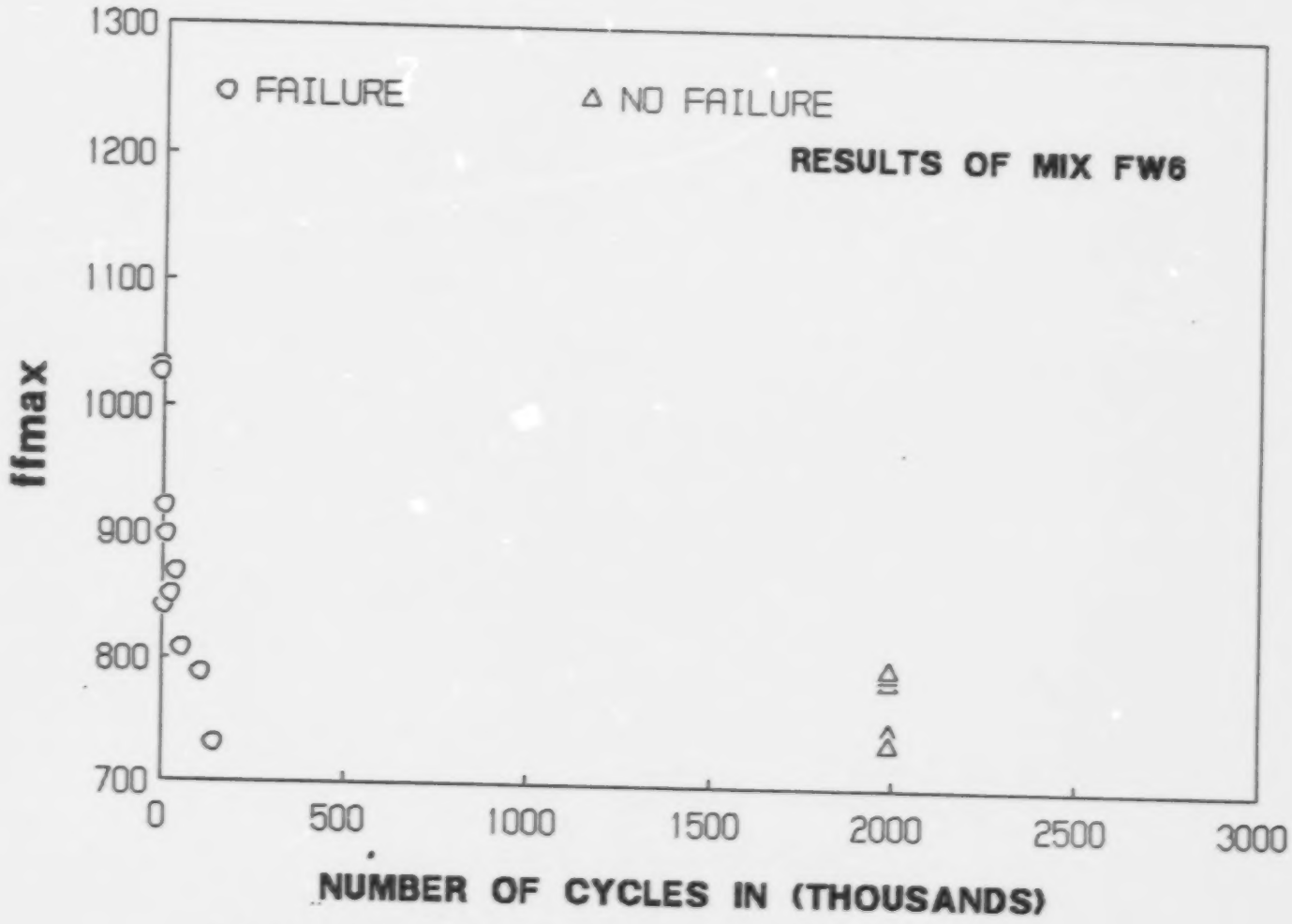

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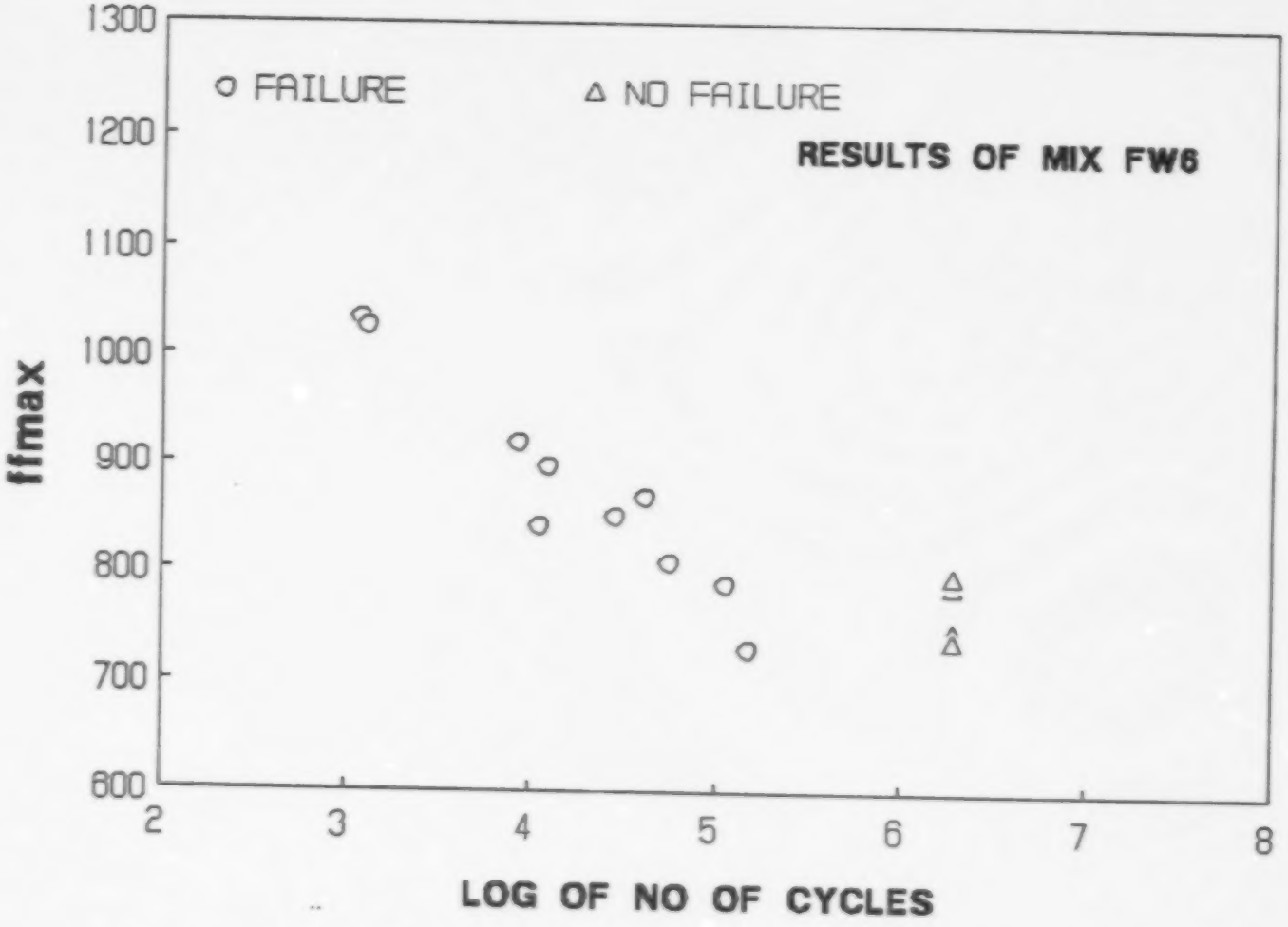

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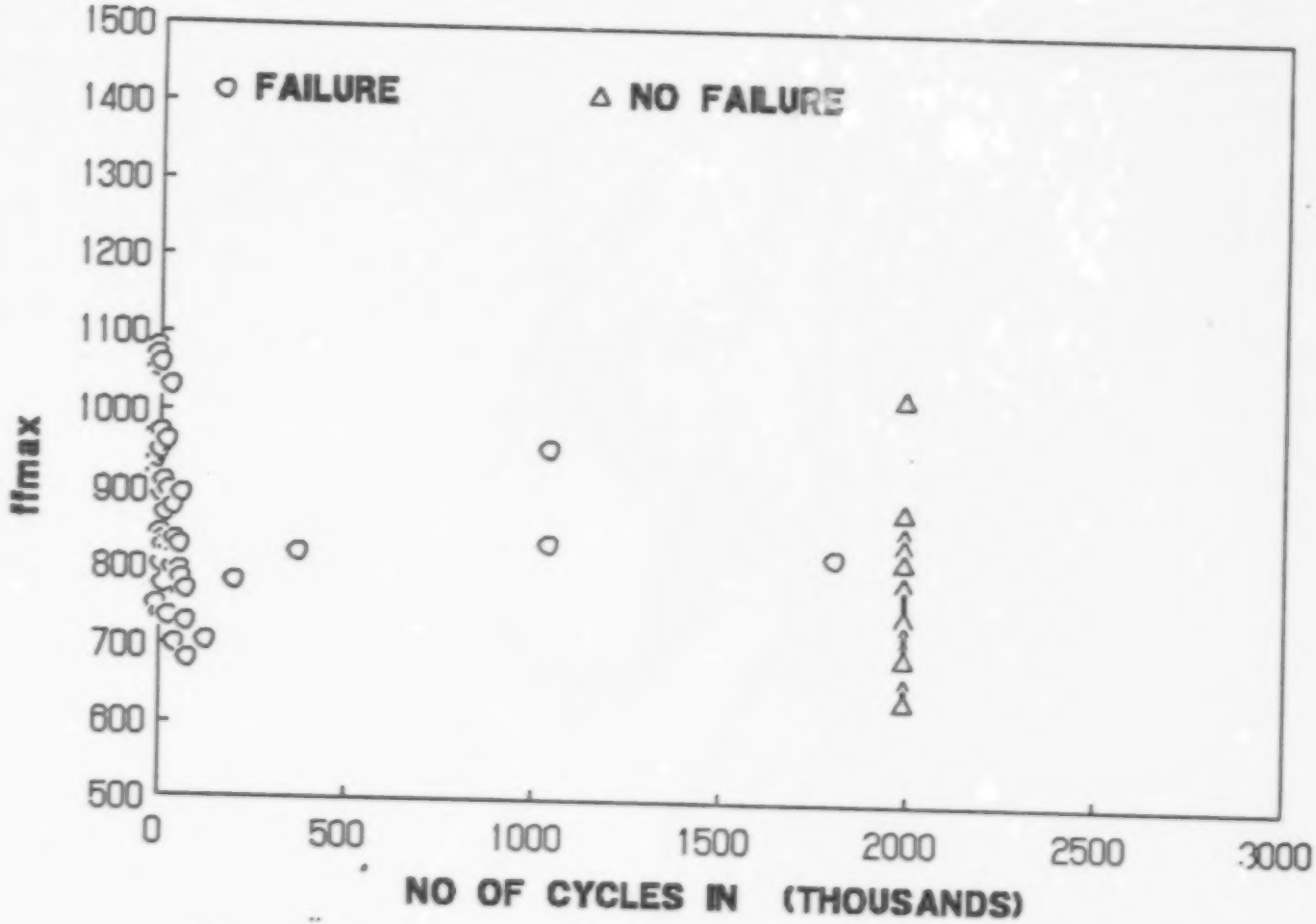

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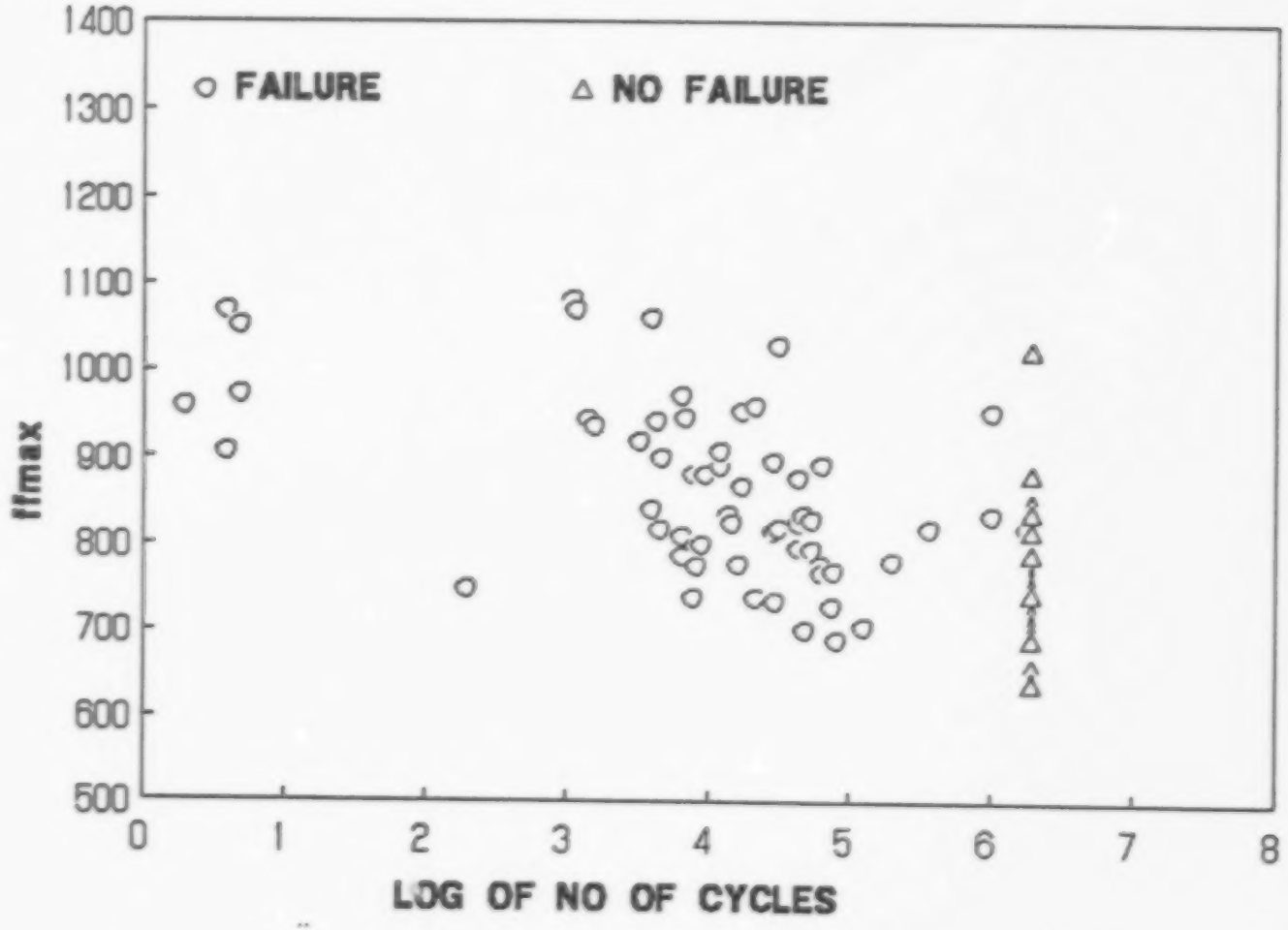

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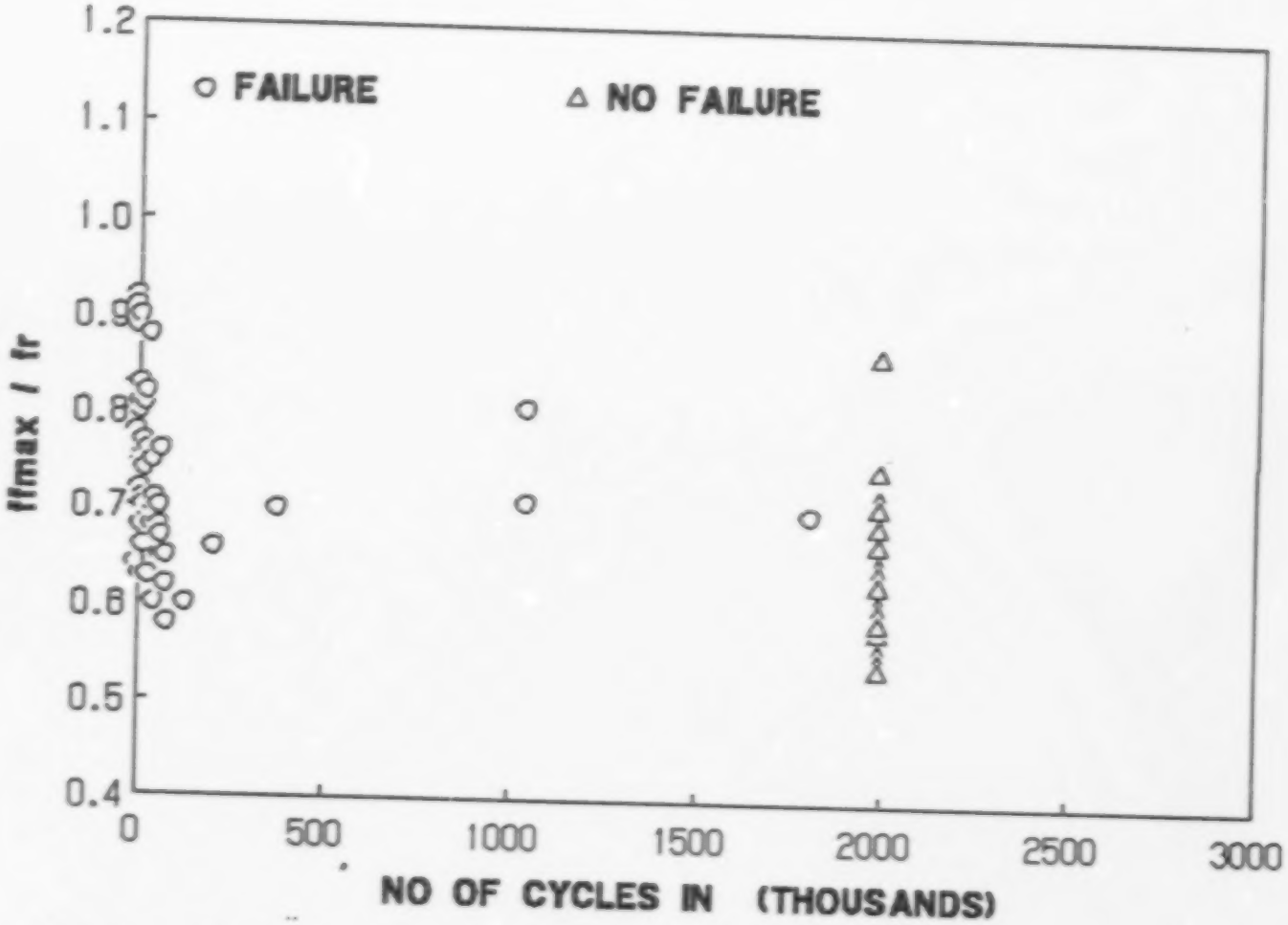

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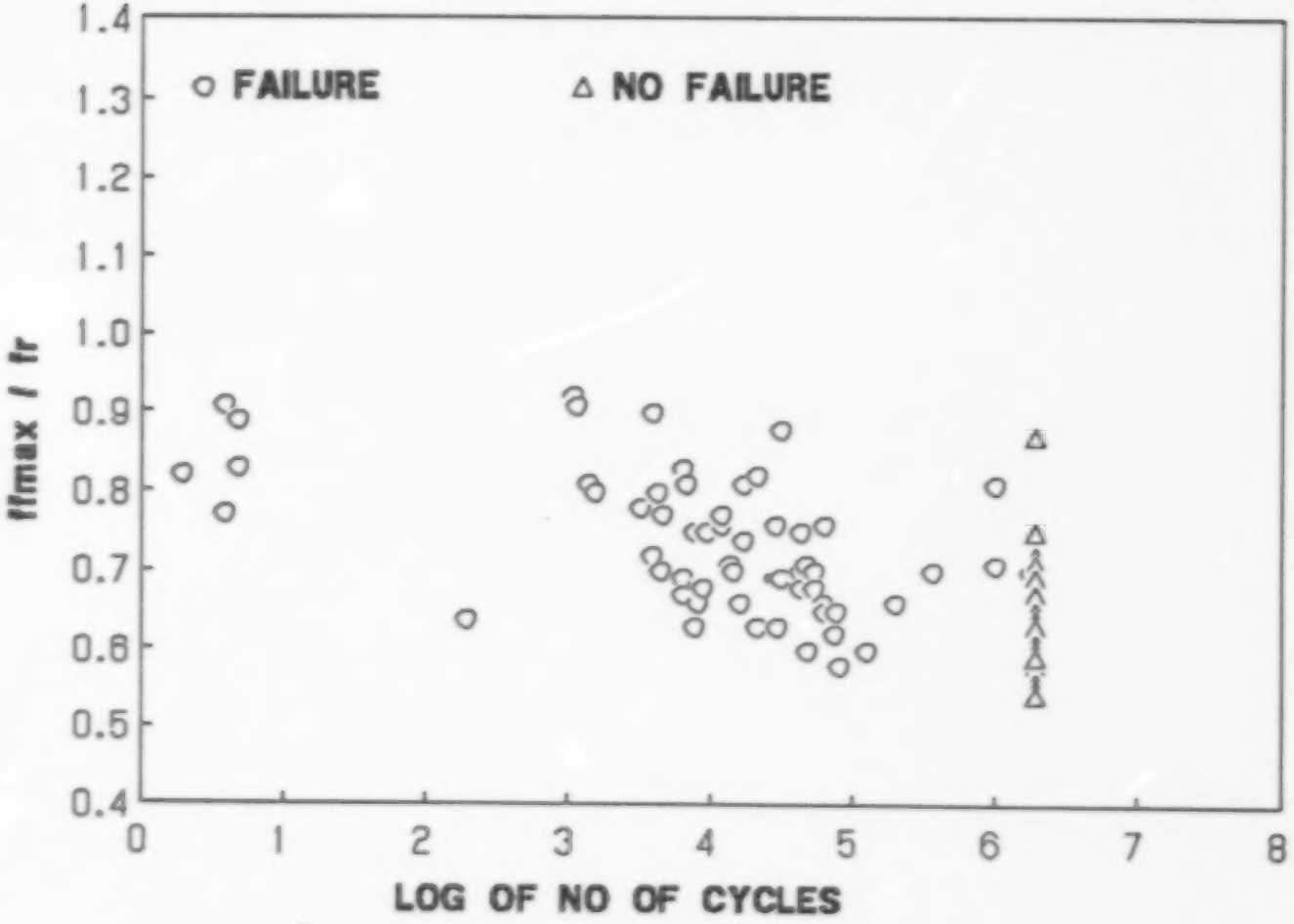

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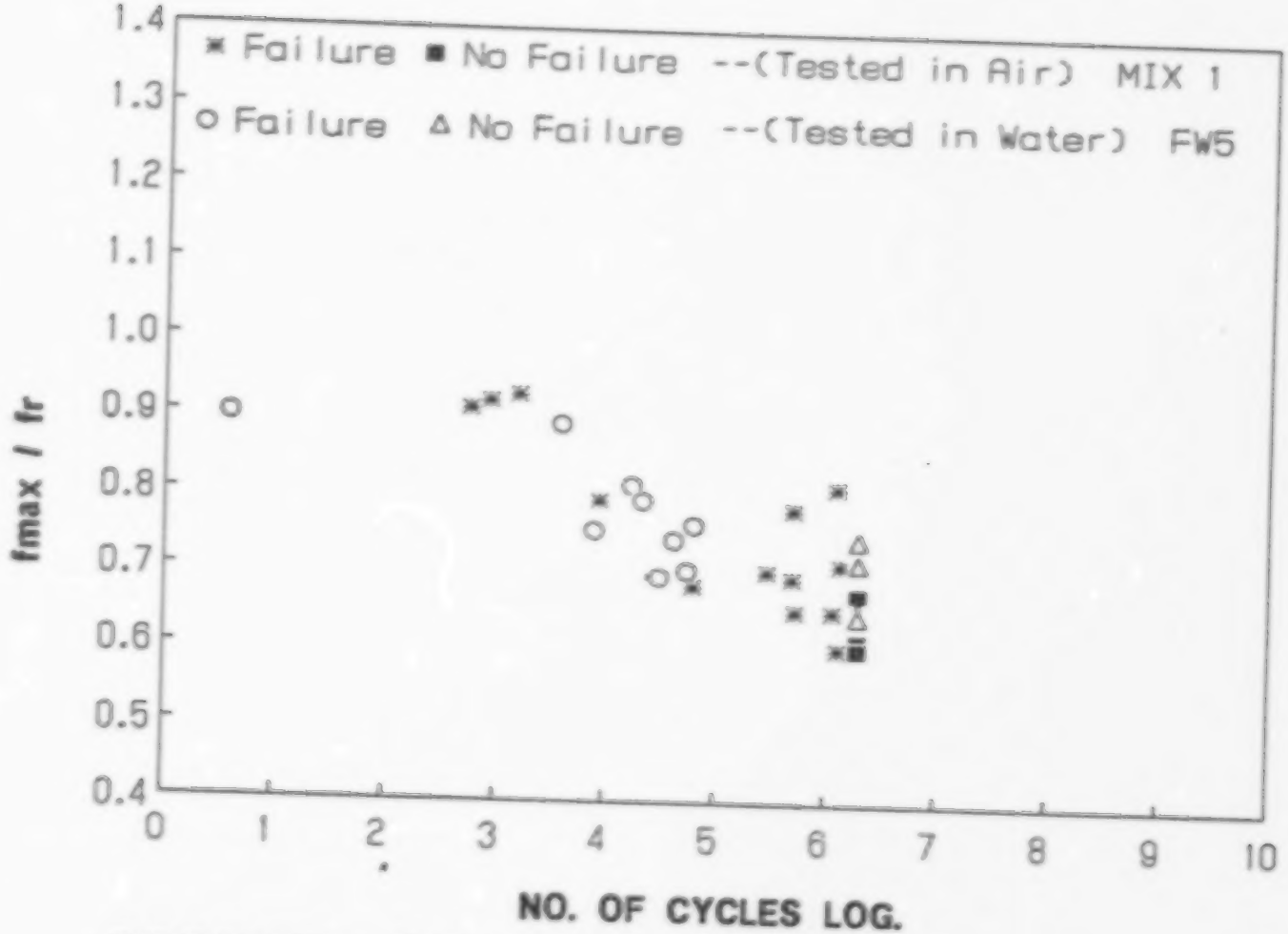

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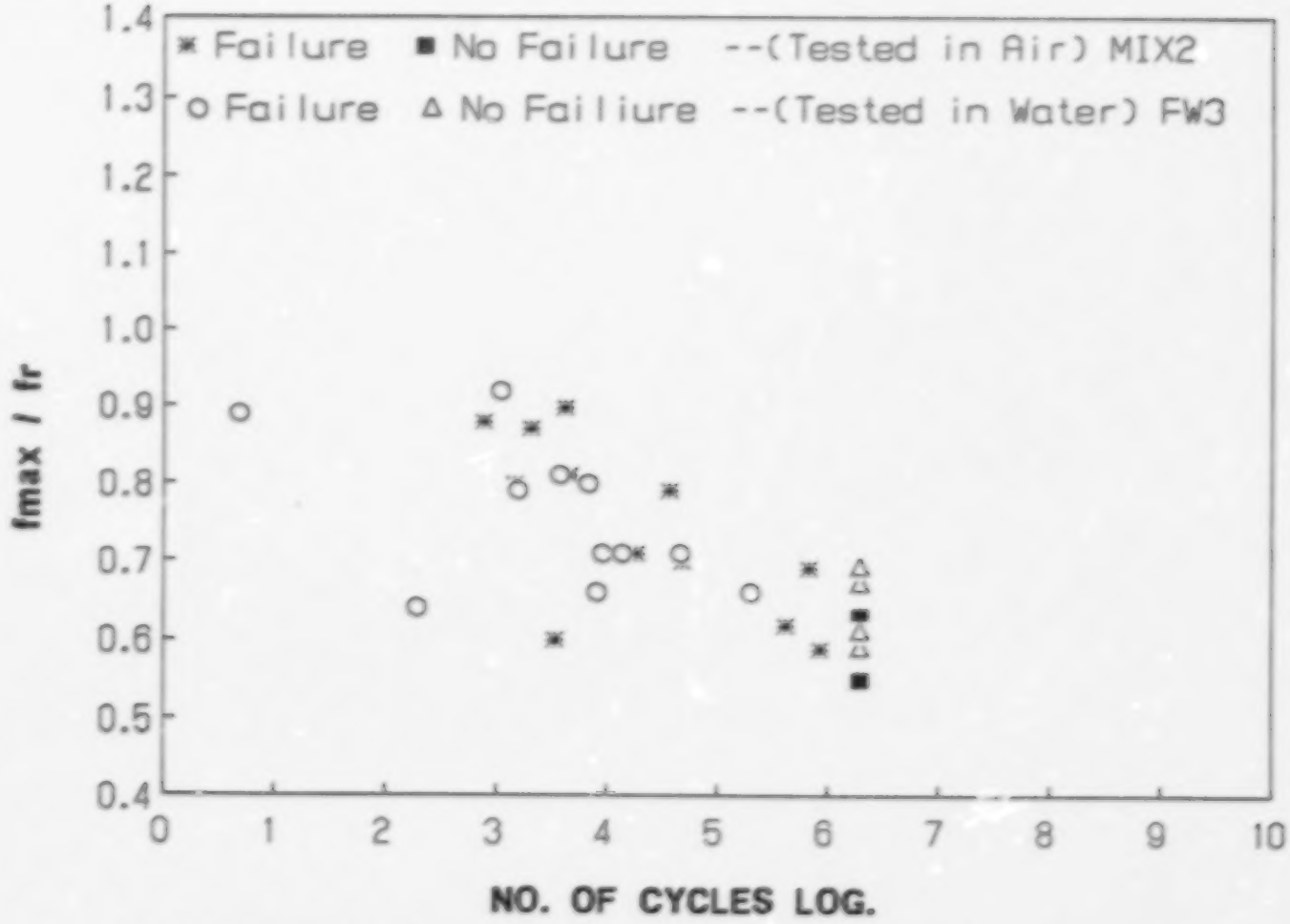

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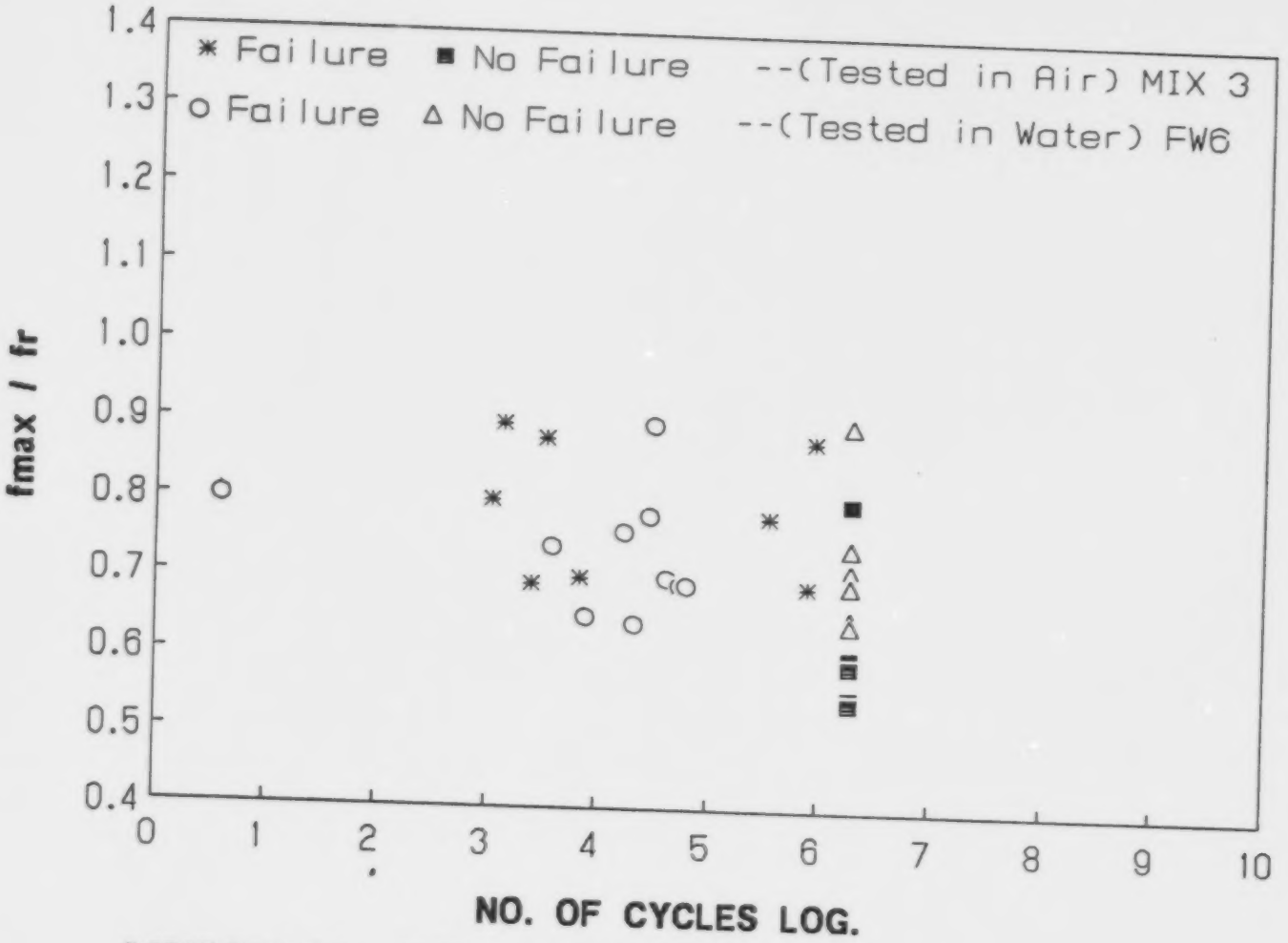

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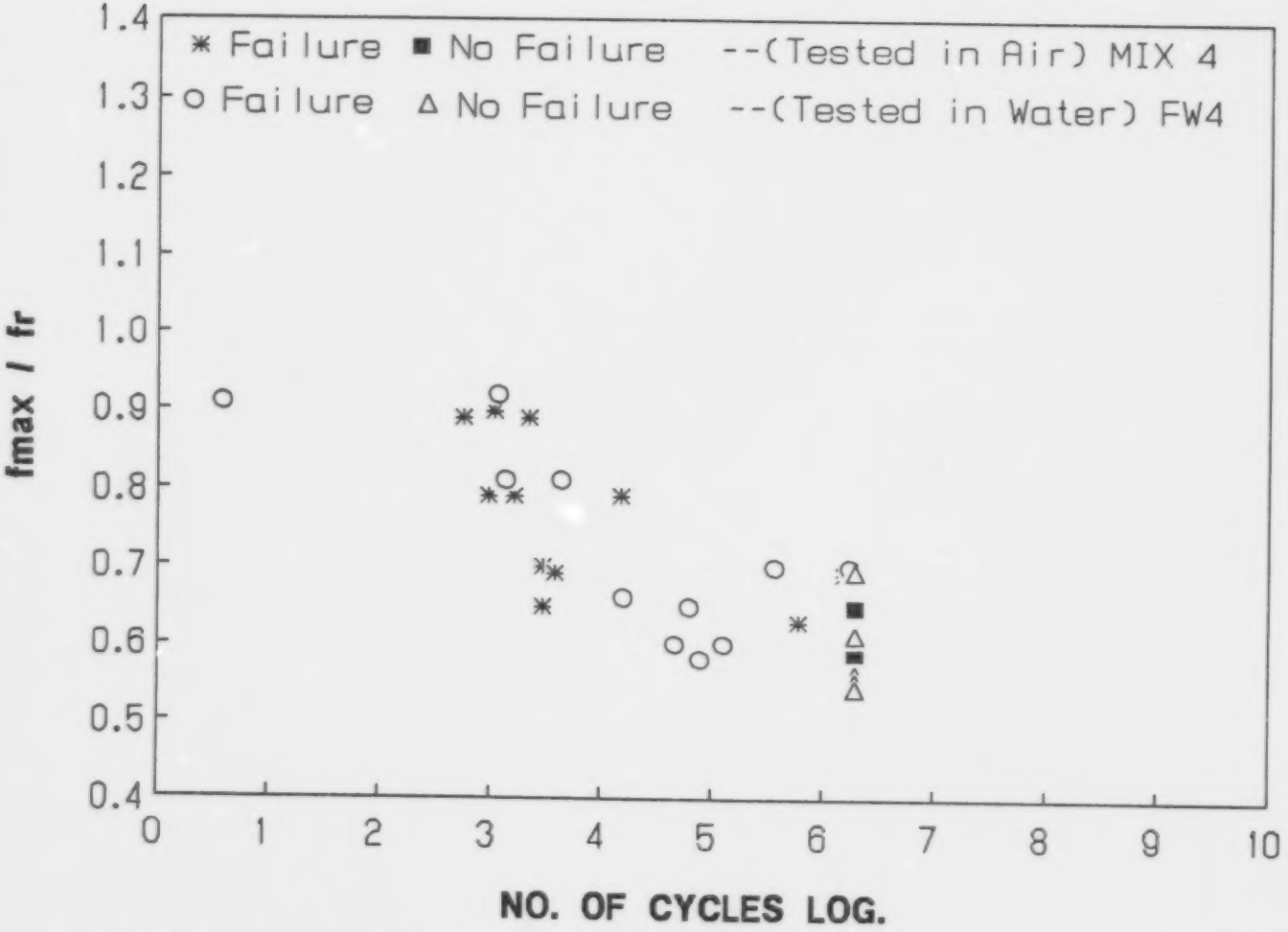

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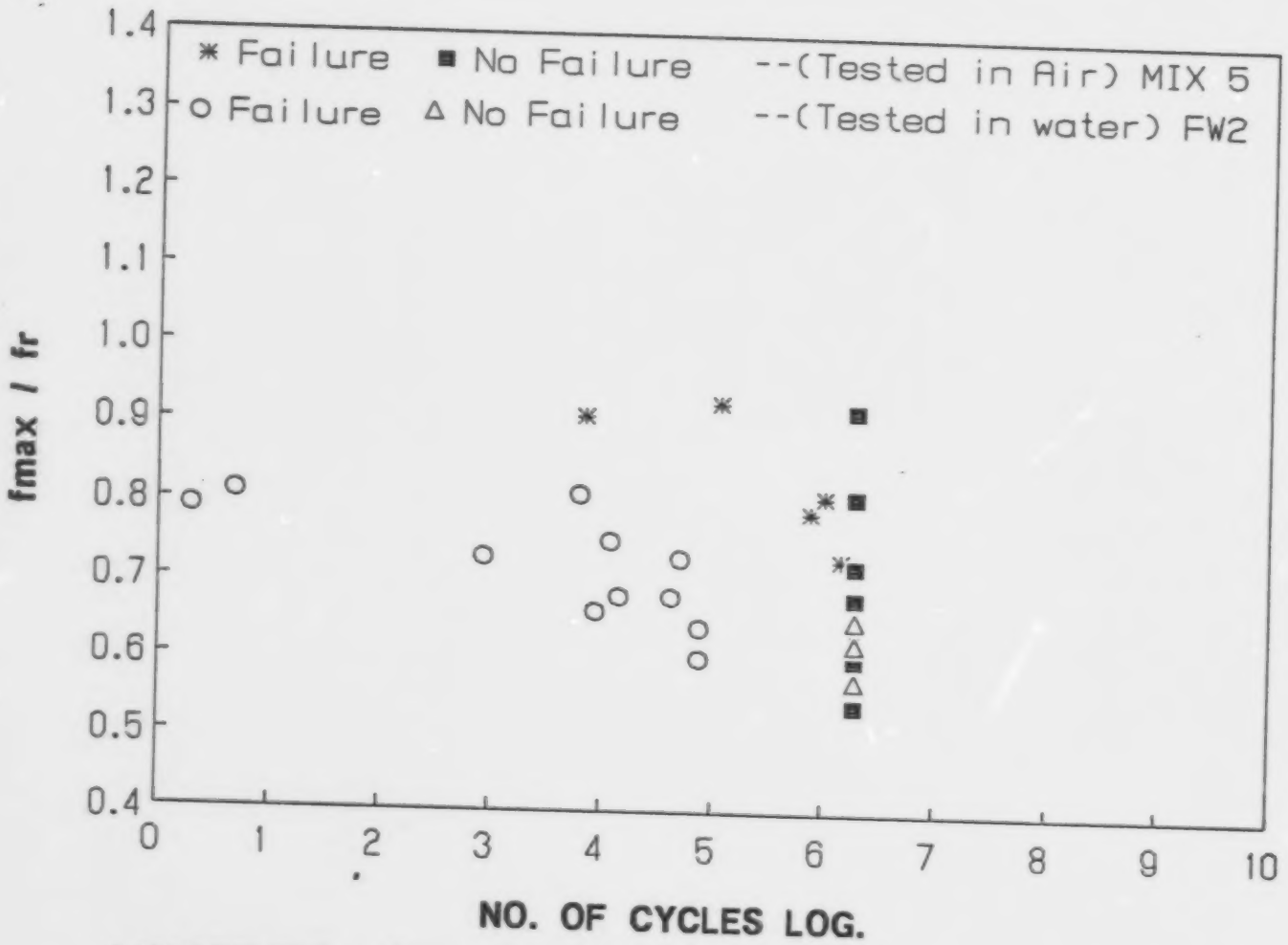

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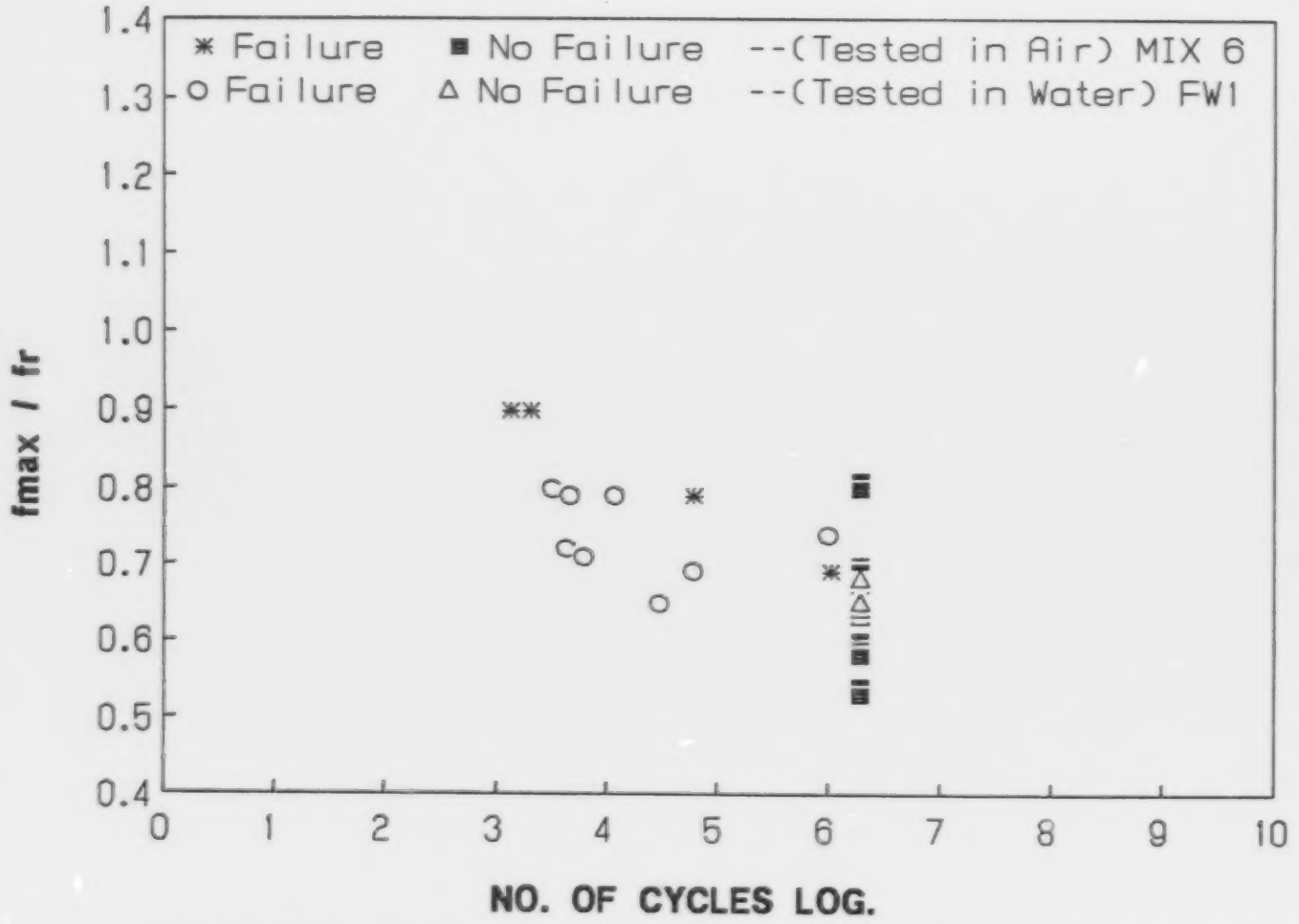

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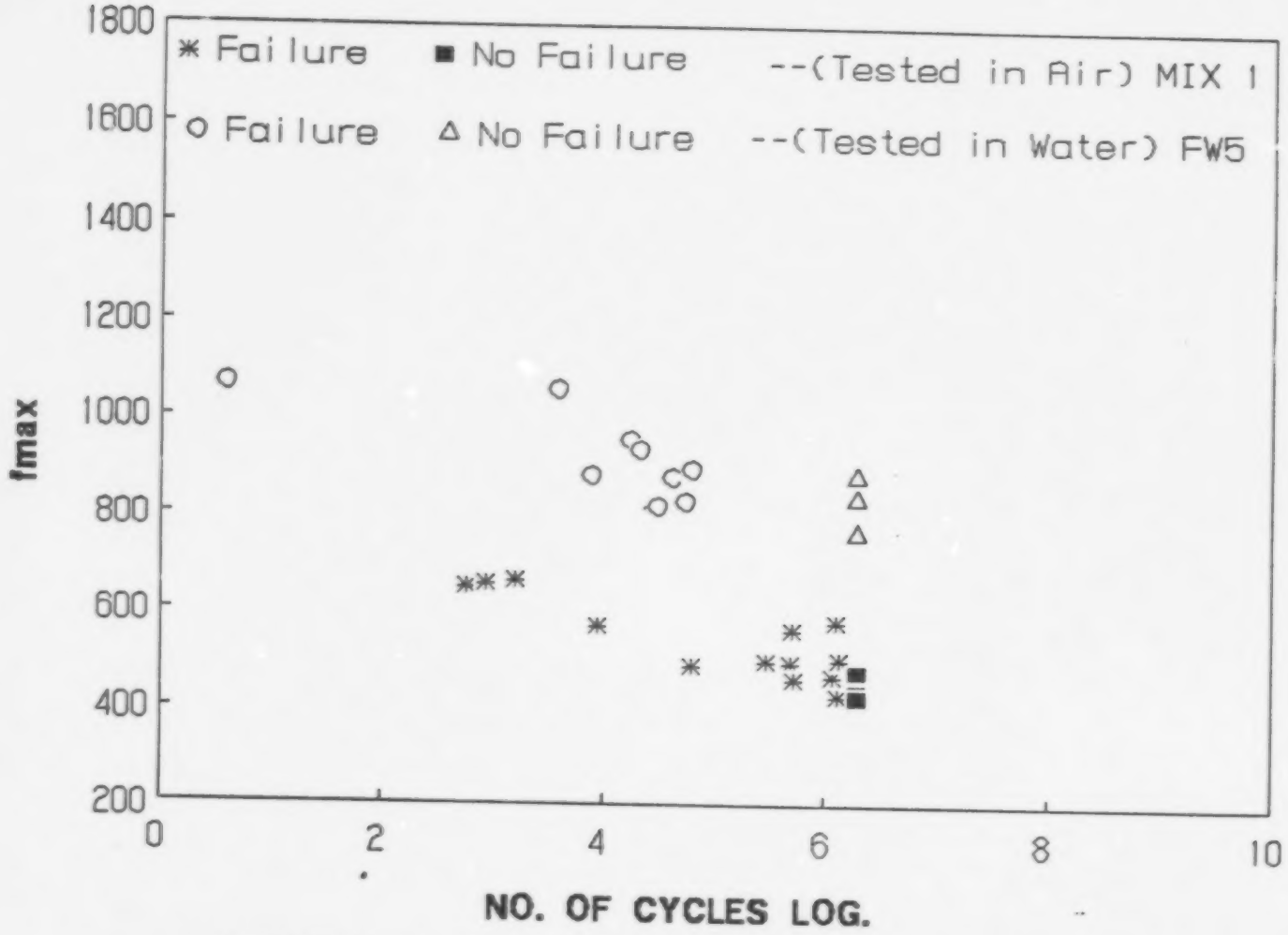

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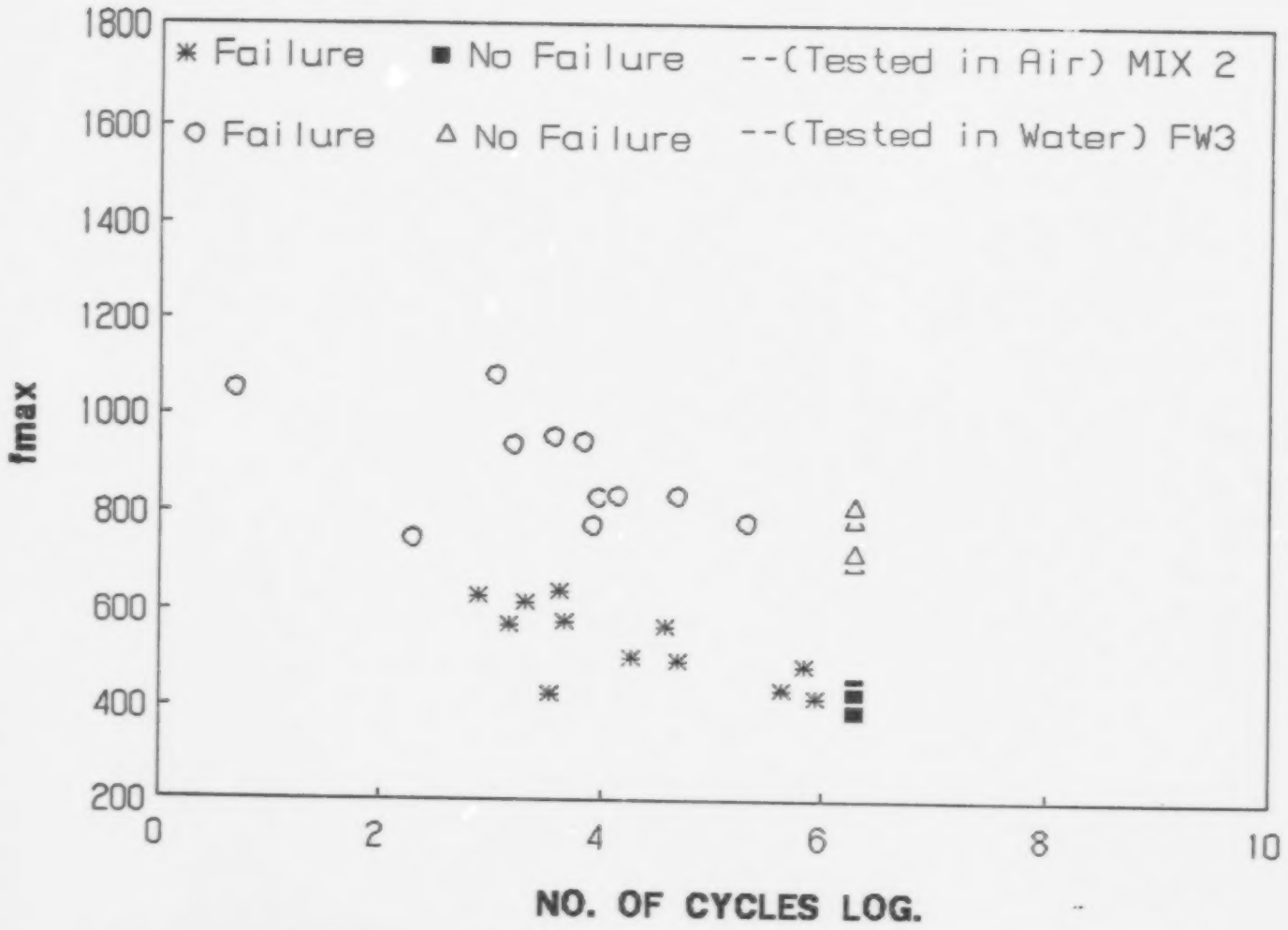

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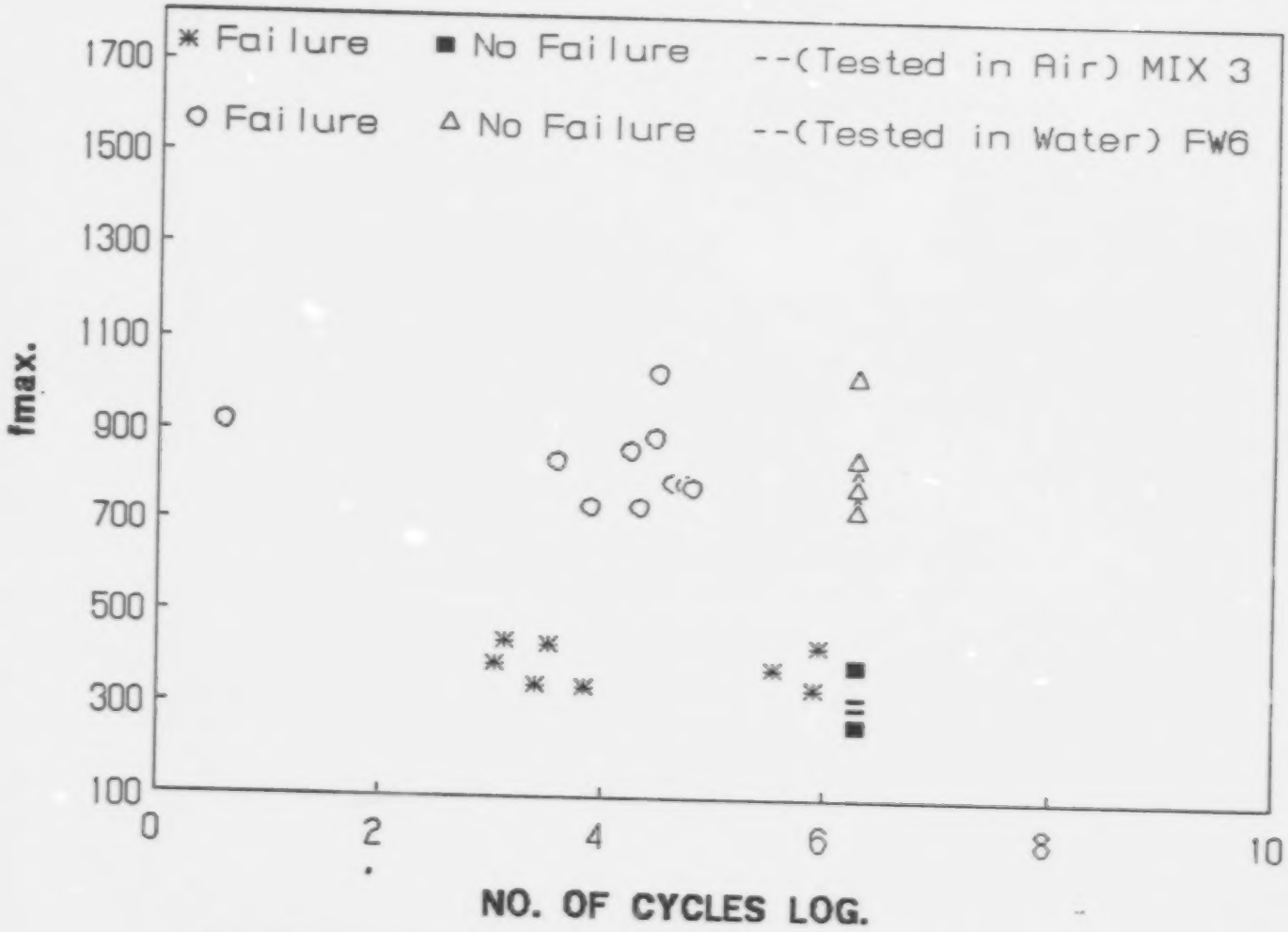

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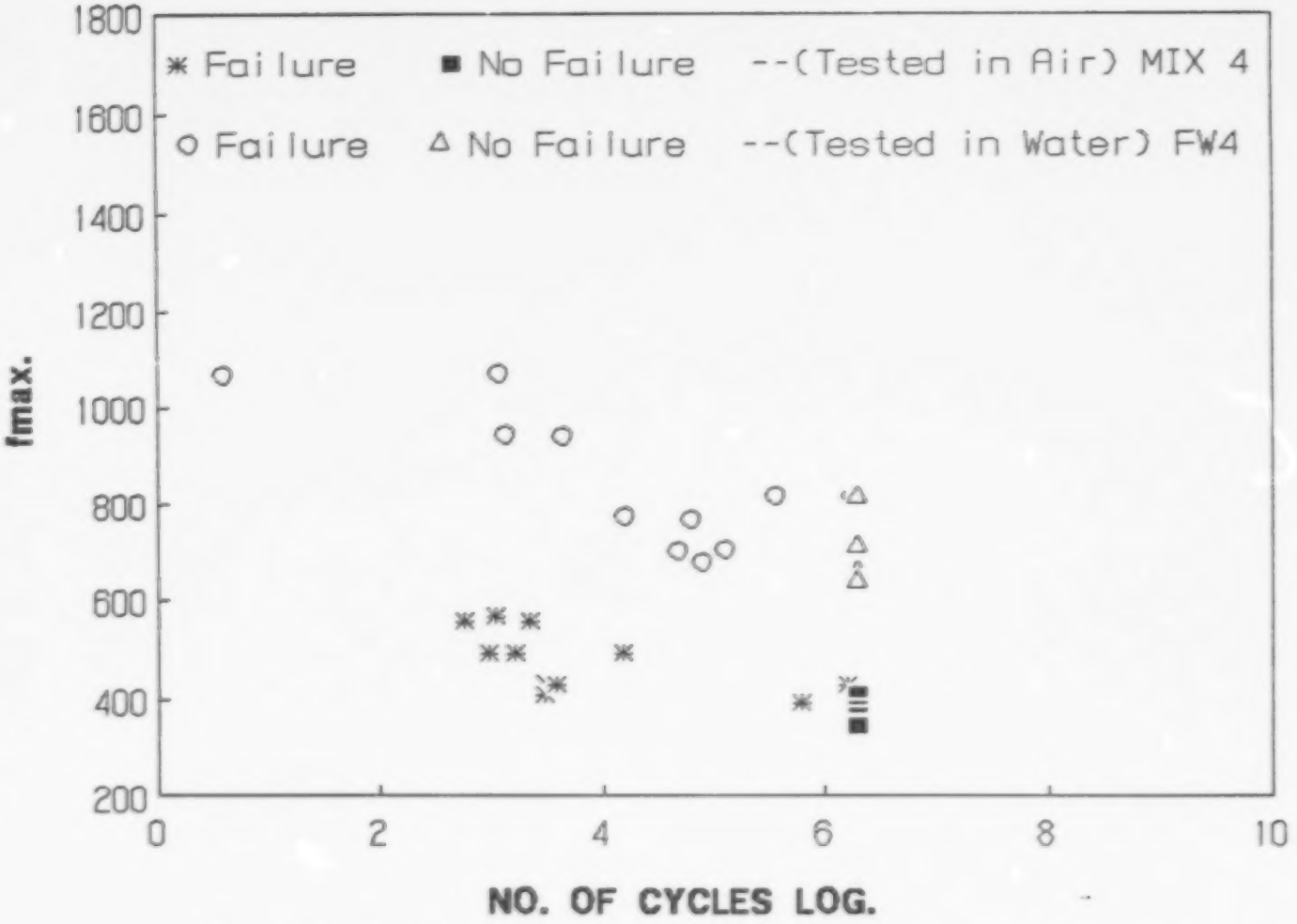

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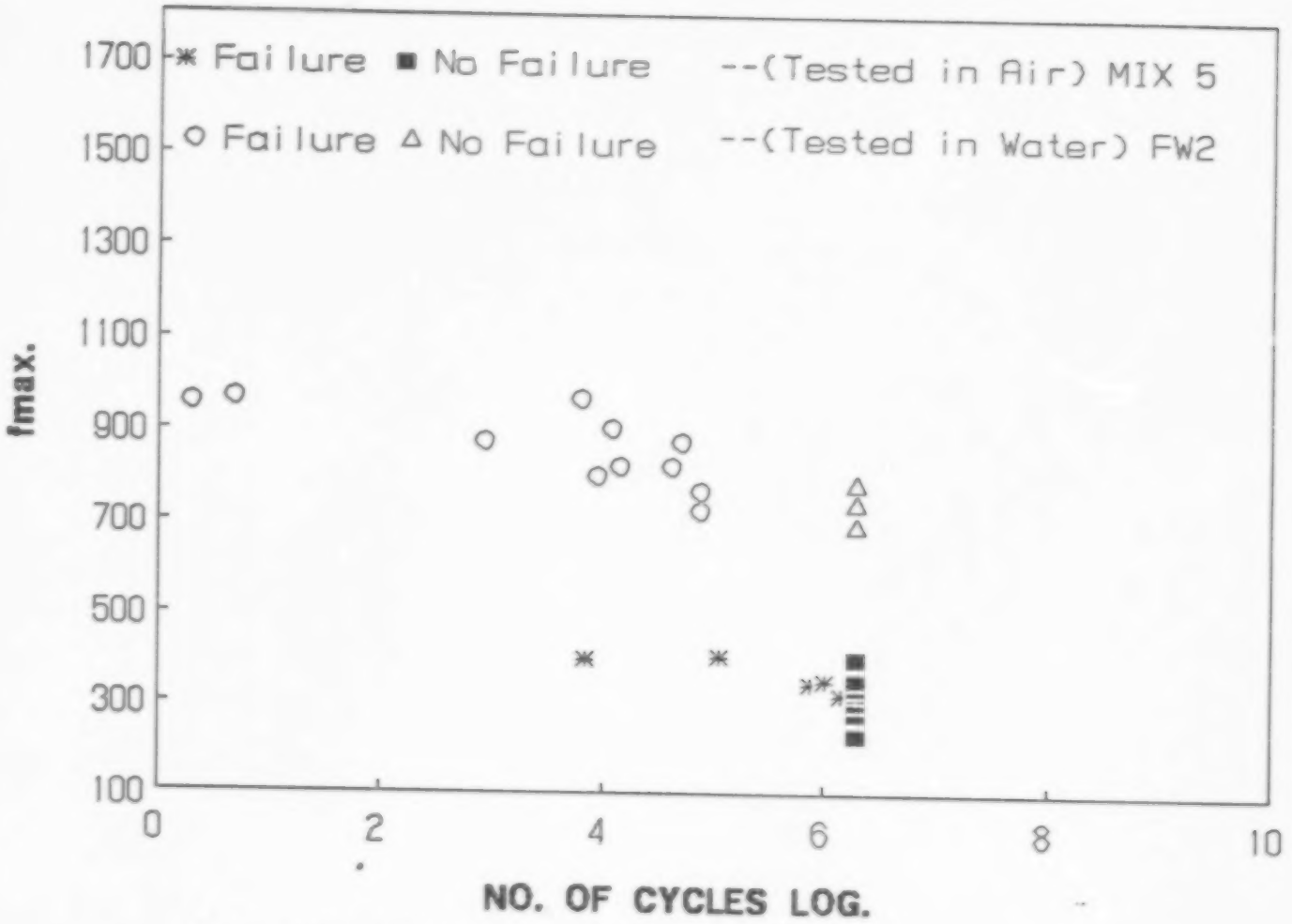

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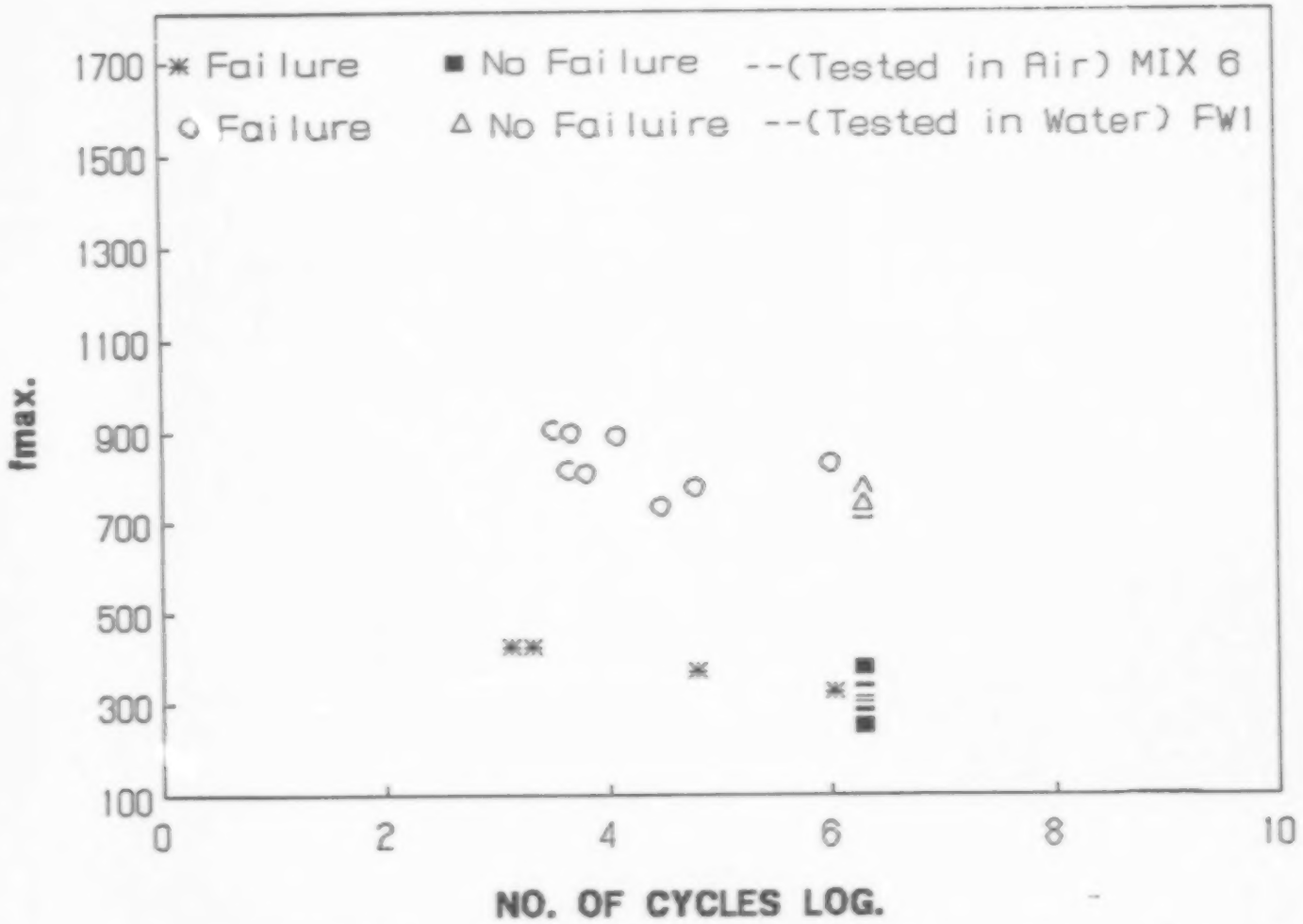
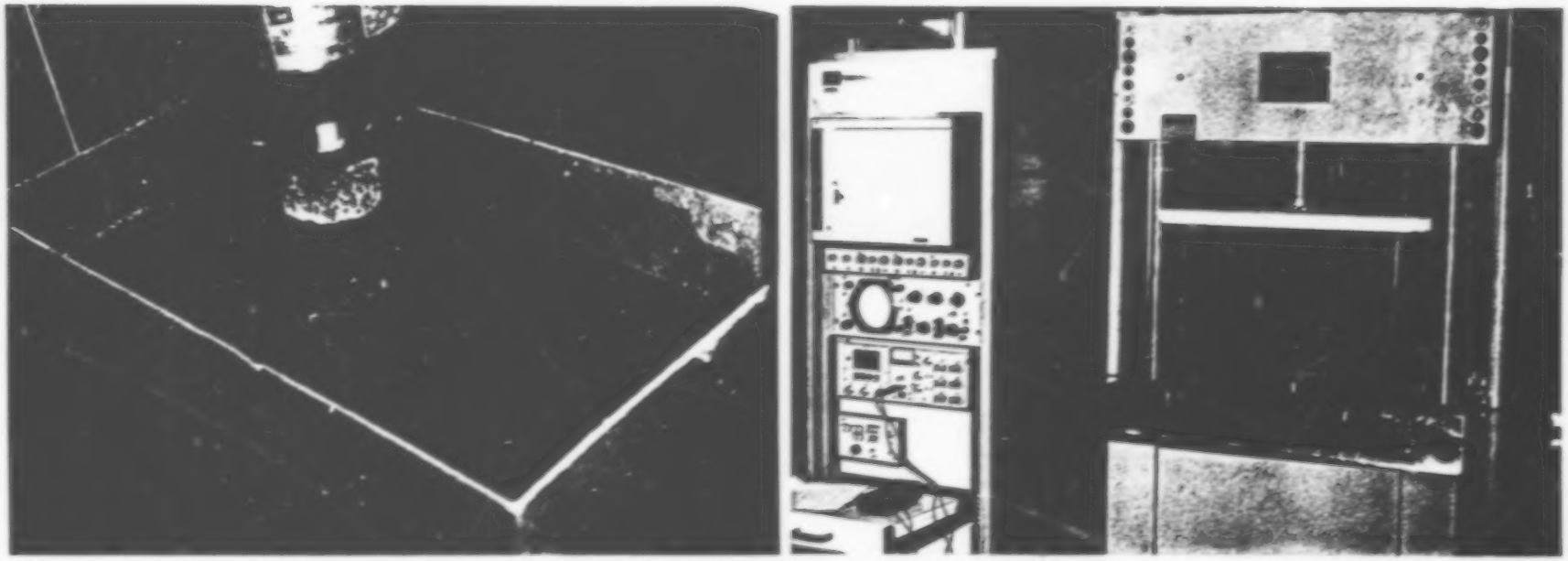
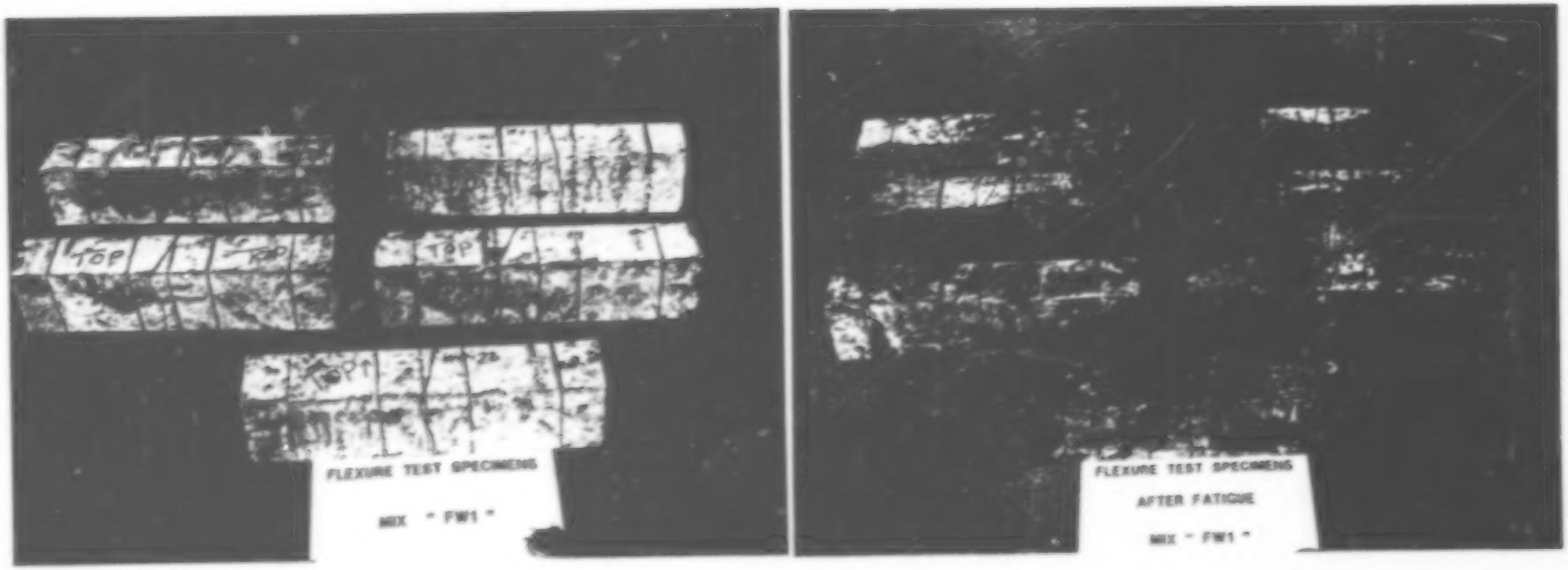


NUMBER OF CYCLES LOG. Vs. fmax.

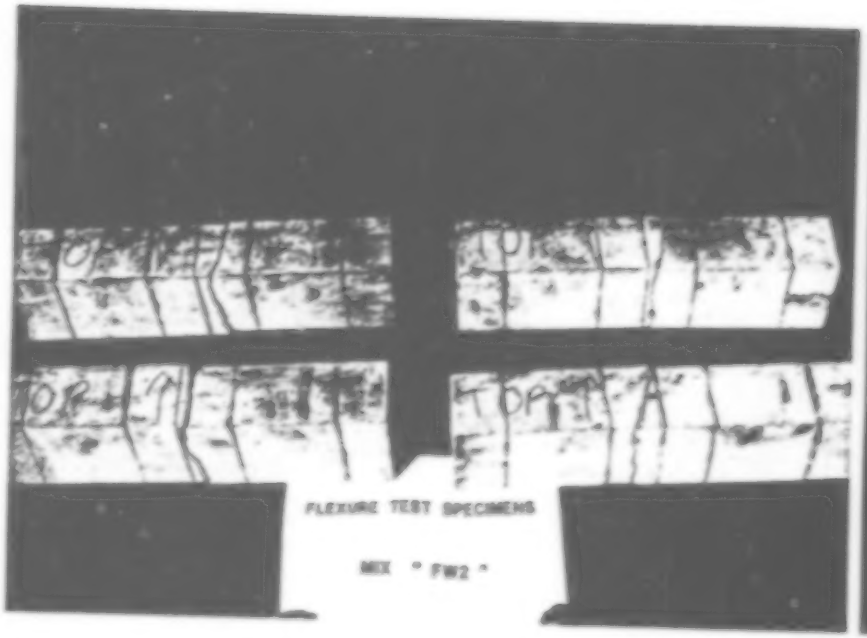


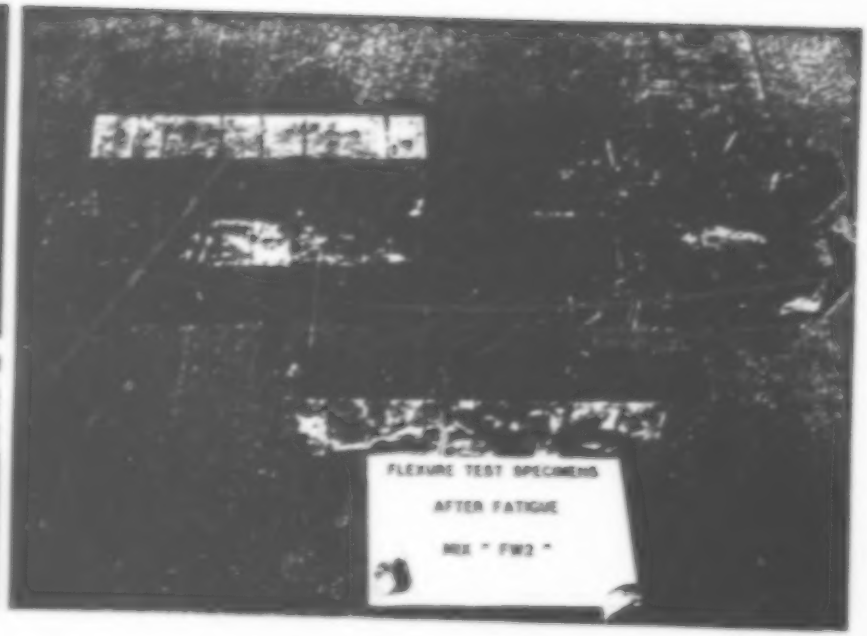
Fatigue Test And Static Test Setup



Static Flexure Test Specimens

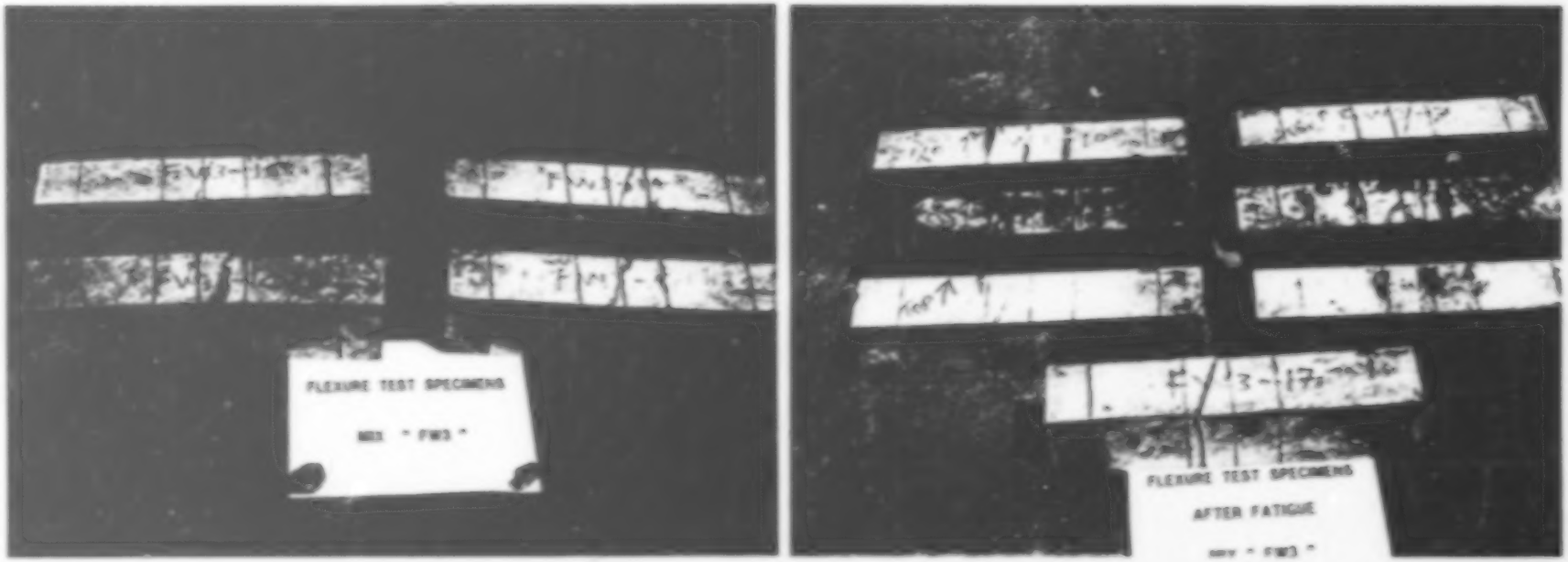
Before And After Fatigue Mix FW1





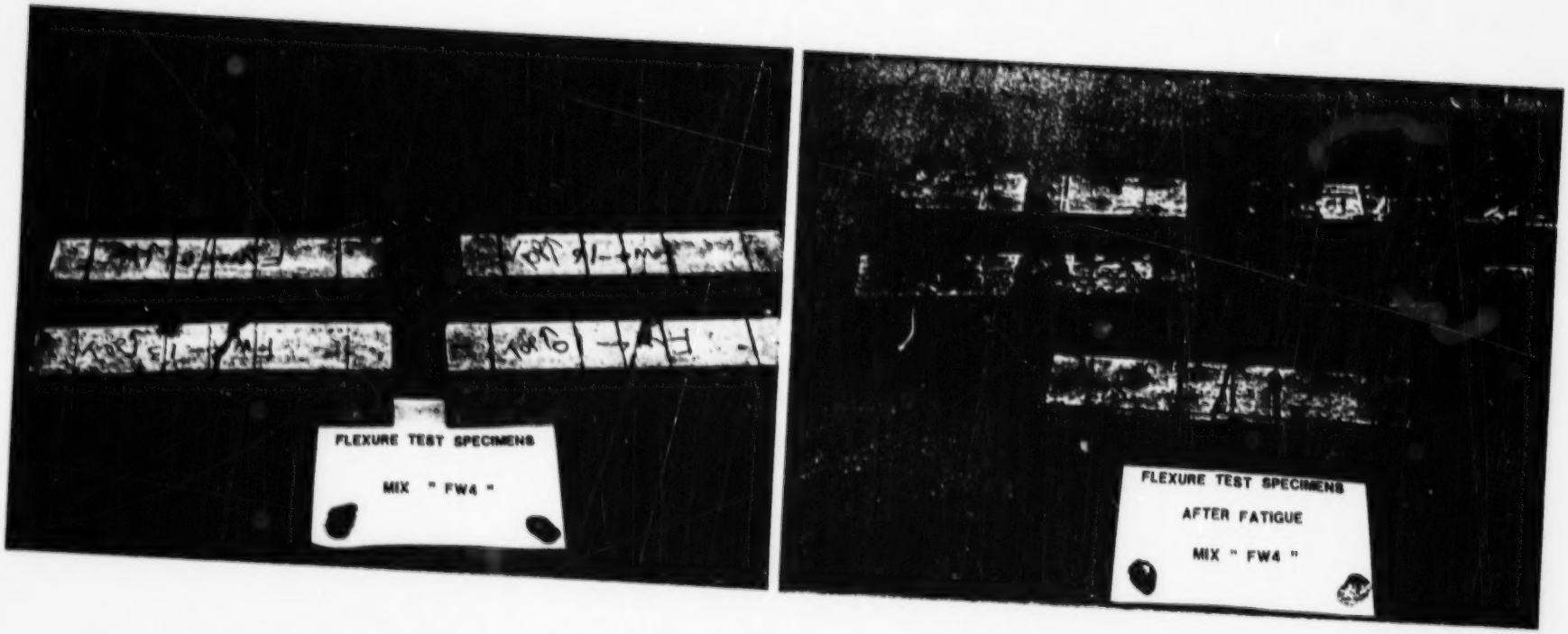
Static Flexure Test Specimens

Before And After Fatigue Mix FW2

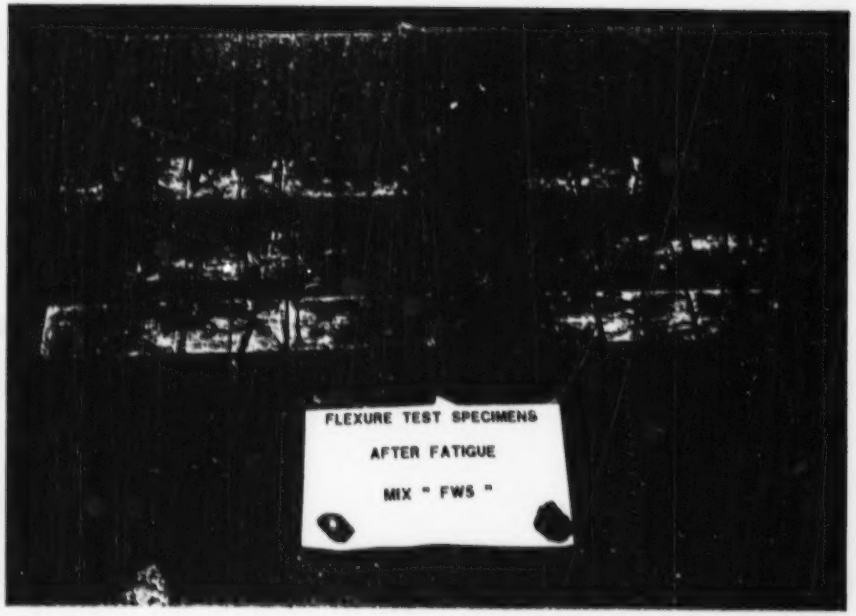


Static Flexure Test Specimens

Before And After Fatigue Mix FW3

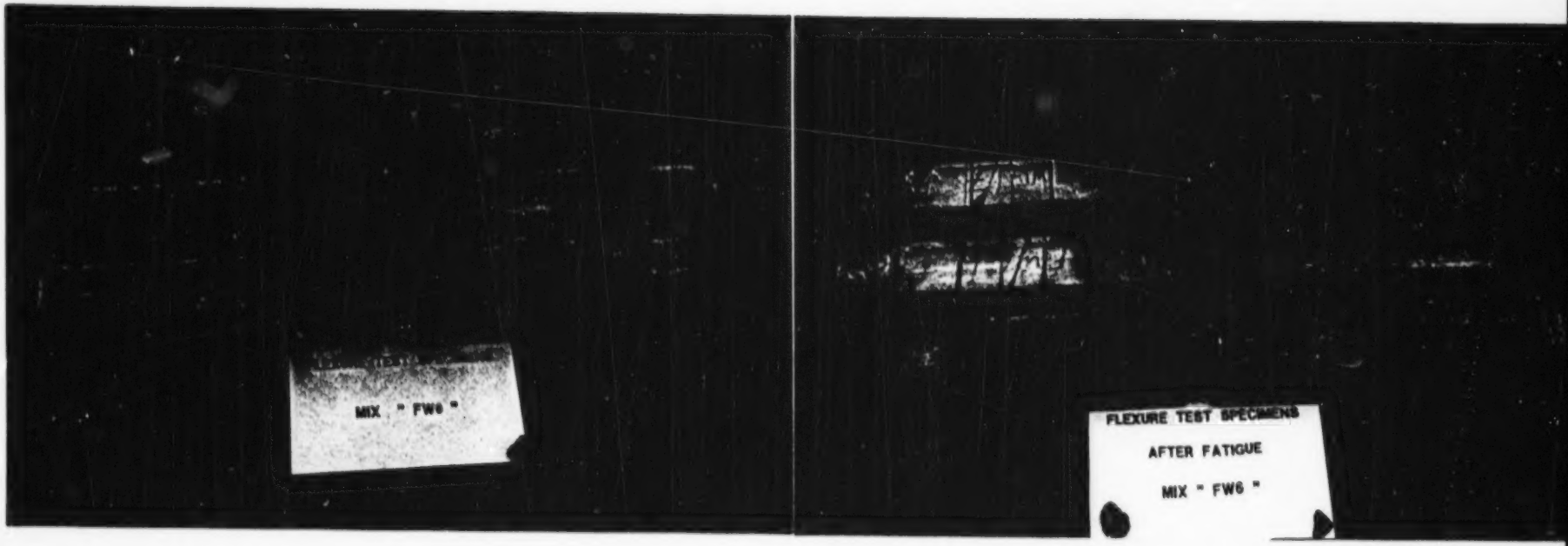


Static Flexure Test Specimens Before And After Fatigue Mix FW4

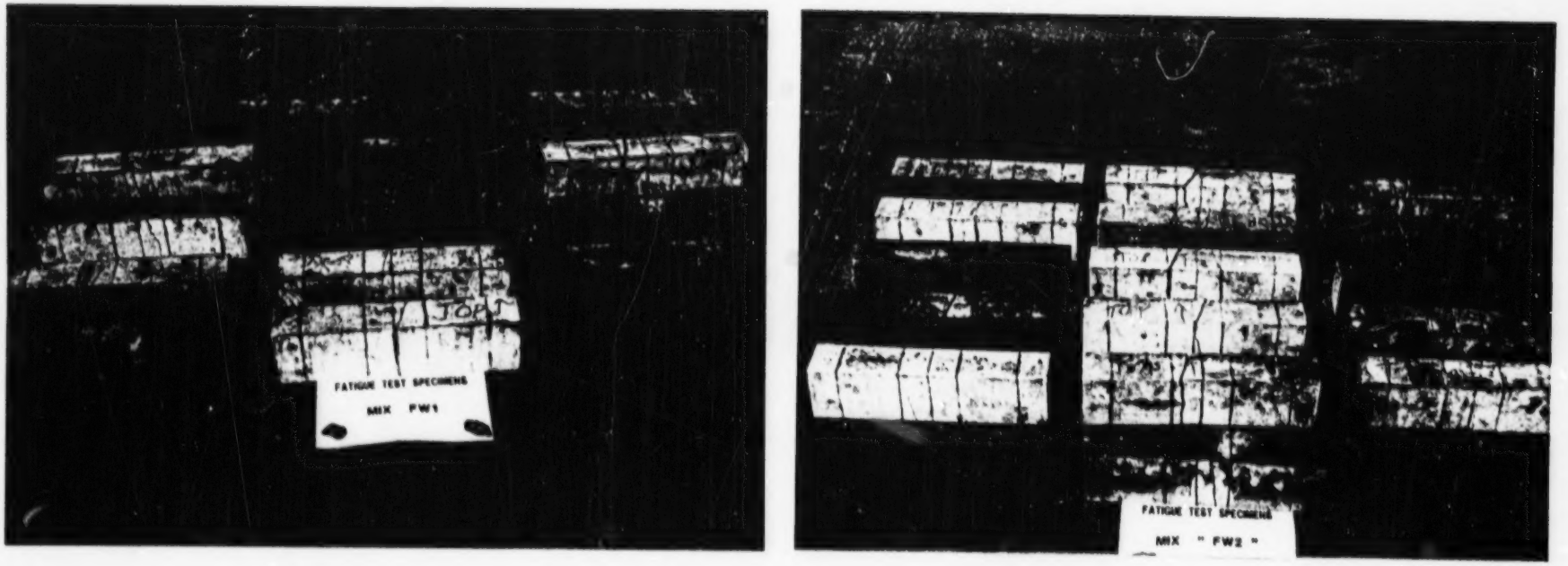


Static Flexure Test Specimens

Before And After Fatigue Mix FW5

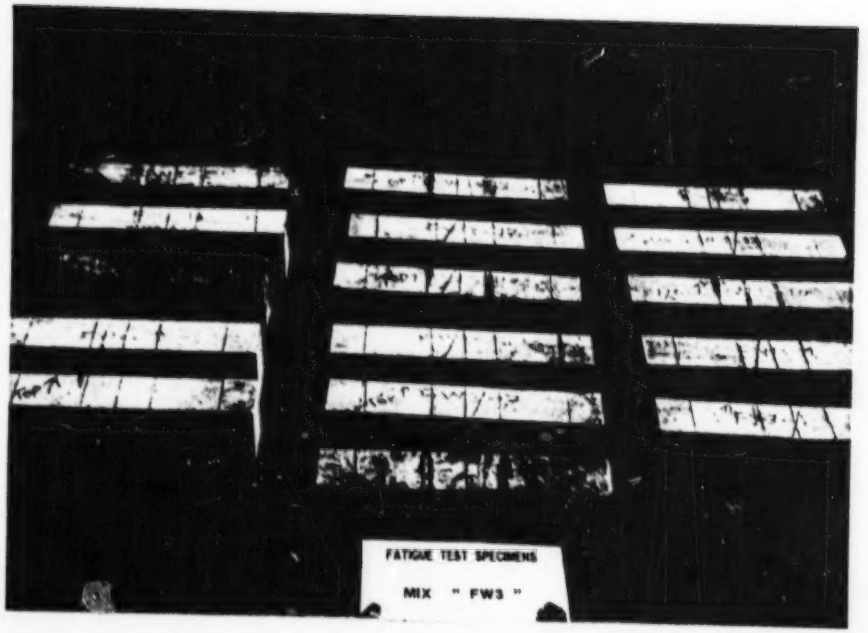


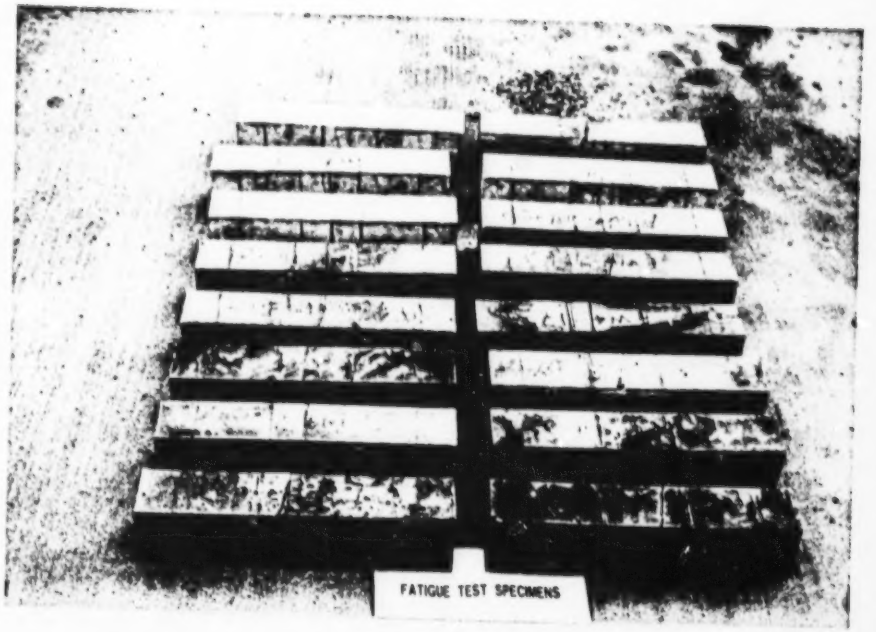
Static Flexure Test Specimens Before And After Fatigue Mix FW6



Fatigue Test Specimens For

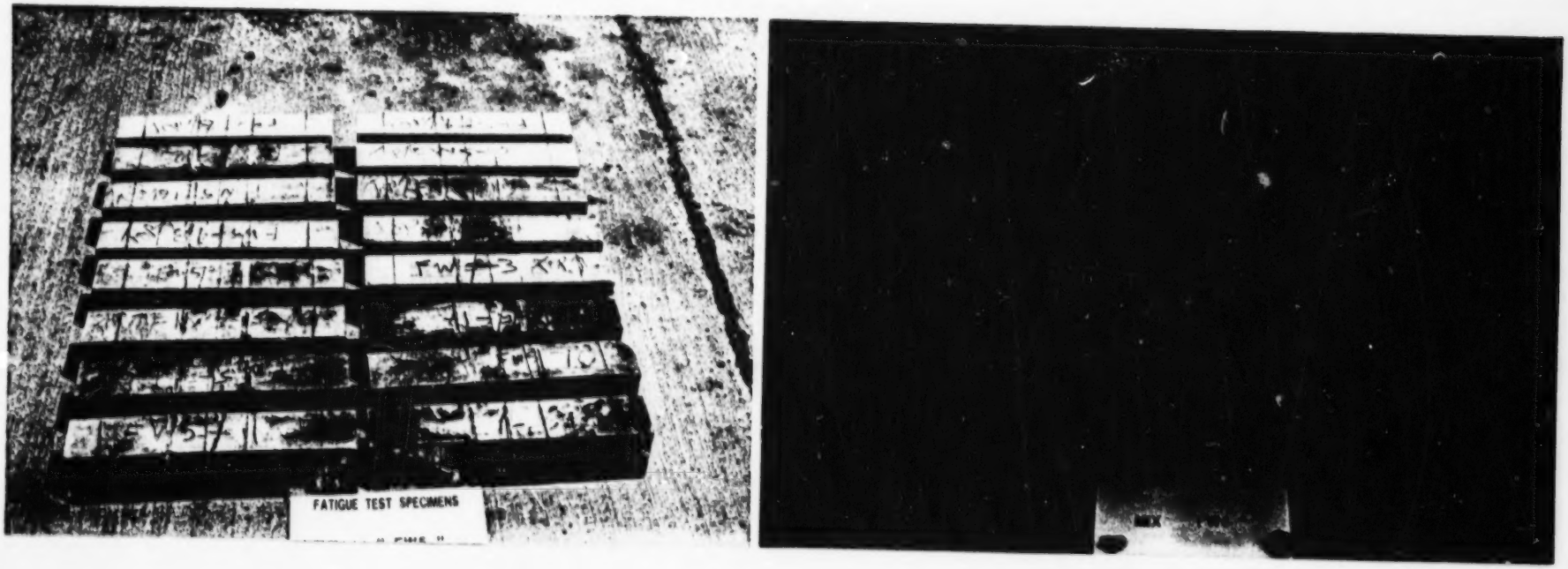
Mix FW1 And FW2





Fatigue Test Specimens For

Mix FW3 And FW4



Fatigue Test Specimens For

Mix FW5 And FW6